# Some Effects of Water Flow Rate and Alevin Density in Vertical Incubation Trays on Early Development of Chinook Salmon (Oncorhynchus tshawytscha)

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TABLE OF CONTENTS


| | | Page |
|---|---|---|
| ABSTRACT | | iv |
| INTRODUCTION | | 1 |
| MATERIALS AND METHODS | | 3 |
| | Fish Quality | 5 |
| | Water Quality | 5 |
| | Ammonia-N Production and Oxygen Consumption Rate Calculation | 5 |
| | Measurement of the Reaeration Coefficient "k" | 8 |
| RESULTS | | 9 |
| | Temperature Unit Data | 9 |
| | Fish Quality | 9 |
| | Mortality | 16 |
| | Water Quality | 16 |
| DISCUSSION | | 22 |
| ACKNOWLEDGEMENTS | | 25 |
| REFERENCES | | 26 |
| APPENDIX I | Average daily temperature and accumulated temperature units from fertilization (day 0) for the incubation of 1976 brood chinook (Year I). | 27 |
| APPENDIX II | Average daily temperature and accumulated temperature units from fertilization (day 0) for the incubation of 1977 brood chinook (Year II). | 29 |
| APPENDIX III | Mean lengths and weights and their standard deviations (SD) for samples of alevins (N) from Year I experiments. | 31 |
| APPENDIX IV | Mean lengths and weights and their standard deviations (SD) for samples of alevins (N) from Year II experiments. | 36 |
| APPENDIX V | Water quality data generated during the study is summarized in these tables. Results for the stacks A, B, C, D, and E are shown for Year I. Year II shows data averaged over two 7-tray stacks loaded at 5500 eggs per tray. | 41 |

## ABSTRACT

Two years of experiments were carried out with chinook salmon (Oncorhynchus tshawytscha) eggs and alevins (1976 and 1977 brood years) at Quinsam Hatchery, Campbell River, B.C. Tests were designed to investigate the relationship between alevin density, water flow rate, and the resultant quality of fry produced during incubation in Heath trays. It was hypothesized that both density and flow rate might have major effects on the activity of alevins incubated in the smooth sided Heath trays. Increased metabolic rates might adversely affect yolk utilization and result in smaller, less viable fry.

In Year I (average water temperature = 8.9°C) alevin weight was found to increase linearly for the first 46 days after hatch (average weight gain = 4.6 mg per day) - it then dropped off if exogenous feeding was not initiated. Weight gains were found to be independent of the initial egg density in the trays. Year II experiments were carried out at an average water temperature of 7.9°C and alevins gained weight at a similar rate (average weight gain = 4.2 mg per day). The lowest weight gain occurred in a group incubated at a low flow (8 liters per min.) and high density (8000 alevins per tray).

During the experiments oxygen, ammonia and pH levels were measured at the inflow and outflow of the Heath stacks being tested. The reaeration effect caused by the water falling between trays was also assessed. These measurements were used to develop a predictive model relating the oxygen concentration at the stack outflow to the alevin metabolic rate, alevin density, water flow rate and the number of trays in the stack.

Alevin oxygen consumption rates in Year I varied from 14 mg per 1000 alevins per hour for eyed eggs near hatch to 120 mg per 1000 alevins per hour for fry near ponding. Ammonia-N production rates on the other hand were much lower -- on average they varied from 0.4 for eyed eggs to 3.2 mg per 1000 alevins per hour for fry.


Key words: chinook salmon, Heath trays, incubation, density, flow.

## RÉSUMÉ

Pendant deux ans, on a mené des expériences sur des oeufs et des alevins (années de génération 1976 et 1977) de saumon quinnat (Oncorhynchus tshawytscha) à la piscifacture Quinsam, à Campbell River (C.-B.). Les essais devaient permettre l'étude des alevins, le débit de l'eau et la qualité résultante des alevins produits par incubation dans des bacs Heath. On a formulé l'hypothèse que la densité et le débit de l'eau avaient des effets majeurs sur l'activité des alevins incubés dans des bacs Heath à bords lisses. Des taux métaboliques accrus peuvent avoir une incidence négative sur l'utilisation du vitellus; ainsi, les alevins sont plus petits et moins viables.

Au cours de la première année (température moyenne de l'eau = 8.9°C), le poids des alevins a augmenté de façon linéaire pendant les 46 premiers jours après l'éclosion (accroissement moyen de poids = 4.6 mg par jour), puis a chuté si une source exogène d'aliments nétait pas fournie. On a découvert que les accroissements de poids étaient indépendants de la densité initiale des oeufs dans les bacs. Les expériences de la deuxième année ont été menées à une température moyenne de l'eau de 7.9°C; les alevins ont grossi à un taux semblable (accroissement moyen de poids = 4.2 mg par jour). C'est un groupe incubé à un faible débit (8 litres par min) et à une densité élevée (8000 alevins par bac) qui a accusé le plus faible accroissement de poids.

Les teneurs en oxygène et en ammoniaque et les niveaux du pH ont été quantifiés à l'entrée et à la sortie des bacs Heath expérimentaux. On a aussi évalué l'incidence de la réaération causée par le déversement de l'eau entre les bacs. Ces quantifications ont servi à l'élaboration d'un modèle prédictif établissant une relation entre la teneur de l'eau en oxygène à la sortie de l'incubateur, d'une part, et, d'autre part, le taux métabolique des alevins, leur densité, le débit de l'eau et le nombre de bacs dans l'incubateur.

Au cours de la première année, les taux de consommation d'oxygène chez les alevins a varié de 14 mg par 1000 individus par heure, chez les oeufs embryonnés prêts à éclore, à 120 mg par 1000 individus par heure, chez les alevins prêts à être libérés en étang. Par contre, les taux de production d'azote ammoniacal ont été beaucoup moins élevés: en moyenne, ils ont varié de 0.4 à 3.2 mg par 1000 individus par heure, chez les oeufs embryonnés et les alevins respectivement.

# INTRODUCTION

Vertically stacked Heath trays are a popular incubation method for fish eggs and alevins. Besides economy of space, this system allows visual inspection of the eggs during incubation and permits easy and accurate control of water flow through the developing eggs. In the mid 1970's the Quinsam Hatchery near Campbell River B.C. (see Fig. 1) was actively using Heath trays for the incubation of chinook salmon eggs. Experiments were performed in this production setting to investigate several aspects of Heath tray incubation.

Fish culturists intuitively have considered it a disadvantage to have smooth sided incubation trays. Such incubators are thought to promote high activity of alevins. It is believed that increased activity may affect yolk utilization and ultimately result in smaller fry. Thus, a reduction in alevin activity is considered advantageous to hatchery production.

Smooth sided incubators with high water velocities are also thought to increase the susceptibility of alevins to yolk sac malformation such as coagulated and elongated yolk sacs (Emadi, 1973). These conditions may cause high mortality rates of alevins or newly ponded fry.

Hatcheries have used three different techniques to reduce alevin activity: 1) reducing water velocities by controlling the flow rate, 2) increasing the alevin density and 3) by adding a substrate, such as gravel, to the incubator. This report deals with the first two techniques; the addition of substrate was not incorporated in these experiments.

Since salmonid alevins are more quiescent when in close contact with their surroundings, high densities might result in alevins using more yolk for growth. Therefore it was hypothesized that higher densities would result in larger fry. Egg densities were experimentally varied around normal production levels to test this hypothesis.

To fulfill oxygen requirements for incubation of larval fish a continuous flow of clean water is required. In a Heath stack the oxygen concentration is reduced as the water flows from the top to the bottom tray. Thus, the relative position of the tray in the stack affects the dissolved oxygen level in the tray. Although the alevins within a tray consume oxygen, fish culturists have recognized that a reaeration effect must exist as the water falls from tray to tray. A model to predict the combined effects of oxygen consumption and reaeration has been developed coincidentally with the Heath tray experiments at Quinsam.

Unfortunately the high water flow rates necessary to maintain adequate dissolved oxygen levels in a multi-tray stack of Heath trays also promoted alevin activity. A second year of experimentation was done with different combinations of water flow rate and egg densities. Tests were carried out to see if activity could be significantly reduced by combining high alevin densities with low water flow rates.

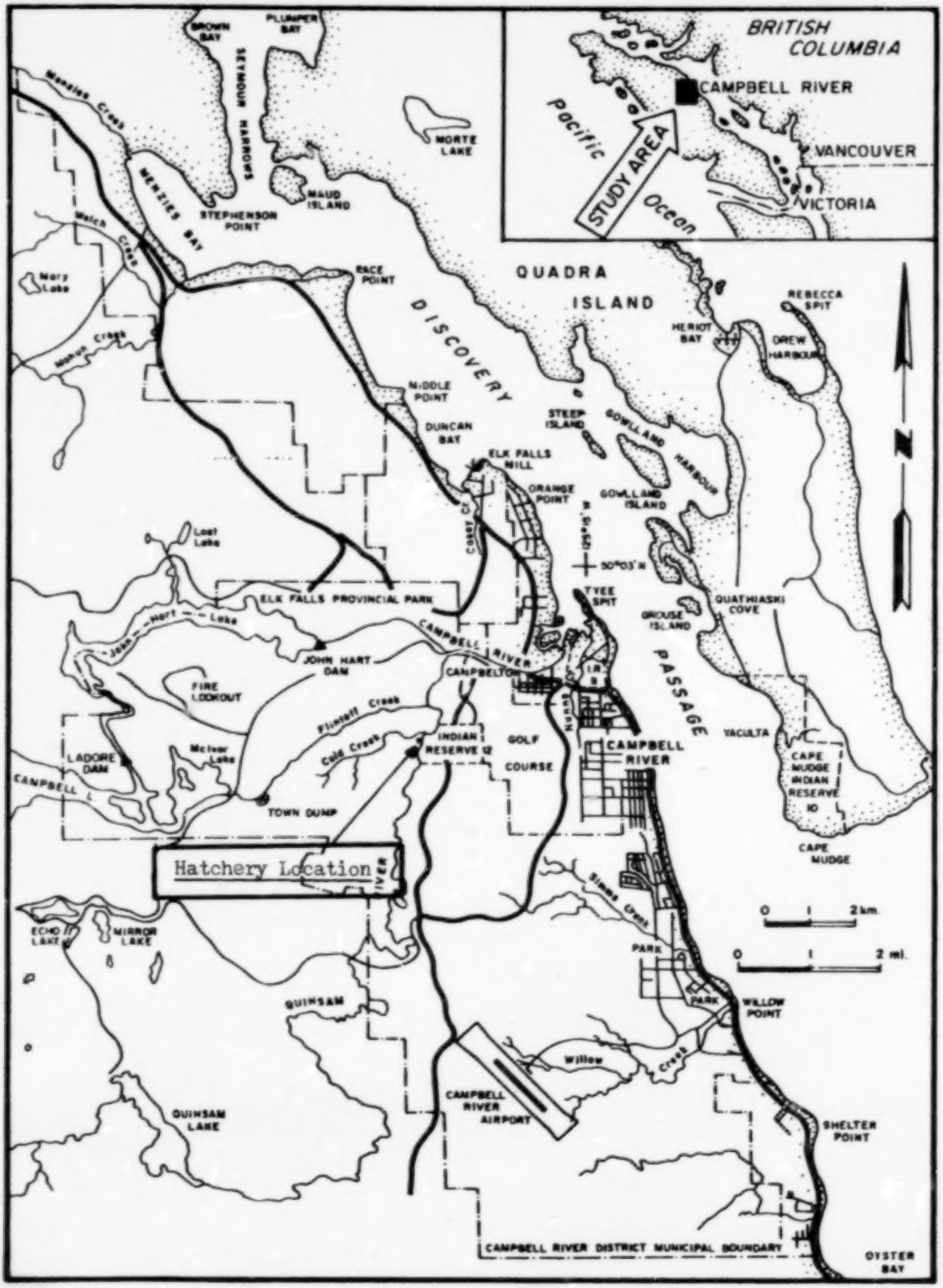


Figure 1: Campbell River Study Area

## MATERIALS AND METHODS

In both experimental years, eggs were taken from wild chinook salmon stock from the Campbell River (Fig. 1) in late October. Incubation occurred at approximately 9° C in the Quinsam Hatchery until early December. At that time eyed eggs were pooled, drained, and weight counted into Heath stacks. Tables 1 and 2 show the two arrangements. The top two trays were left empty because of air entrainment and sedimentation problems. Water entered the stacks from a common head-box.

Table 1. Year I (1976 Brood) distribution of eyed chinook salmon eggs in Heath stacks.

| STACK | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| FLOW l/min | 12 | 12 | 12 | 12 | 12 | 12 |
| Tray # | | | | | | |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 3005 | 4252 | 5499 | 6745 | 7992 | 0 |
| 4 | 3005 | 4252 | 5499 | 6745 | 7992 | 0 |
| 5 | 3005 | 4252 | 5499 | 6745 | 7992 | 0 |
| 6 | 3005 | 4252 | 5499 | 0 | 0 | 0 |
| 7 | 3005 | 4252 | 0 | 0 | 0 | 0 |
| 8 | 3005 | 0 | 0 | 0 | 0 | 0 |
| 9 | 3005 | 0 | 0 | 0 | 0 | 0 |
| 10 | 3005 | 0 | 0 | 0 | 0 | 0 |
| TOTAL | 24040 | 21260 | 21996 | 20235 | 23976 | 0 |

In year I, eggs were fertilized on Oct. 29, 1976. Eyed eggs were pooled and distributed on Dec. 2, 1976, 324°C-days after fertilization. At this time dead eggs were removed and the eyed egg weight was measured. The average wet weight per egg was 449 mg (standard deviation(SD) = 79 mg, coefficient of variation = 18%). It was estimated that 50% hatch occurred on Dec. 23, 1976, at 521°C-days. Fish were moved to rearing ponds on Feb. 11, 1977, at 956°C-days.

Table 2. Year II (1977 Brood) distribution of eyed chinook salmon eggs in Heath stacks.

| STACK | C | D | E | F | G | H | I |
|---|---|---|---|---|---|---|---|
| FLOW l/min | 12.0 | 12.0 | 8.0 | 8.0 | 12.0 | 16.0 | 16.0 |
| Tray # | | | | | | | |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 5500 | 5500 | 0 | 0 | 0 | 0 | 0 |
| 4 | 5500 | 5500 | 0 | 0 | 0 | 0 | 0 |
| 5 | 5500 | 5500 | 0 | 0 | 0 | 0 | 0 |
| 6 | 5500 | 5500 | 0 | 0 | 0 | 0 | 0 |
| 7 | 5500 | 5500 | 0 | 0 | 0 | 0 | 0 |
| 8 | 5500 | 5500 | 0 | 0 | 0 | 0 | 0 |
| 9 | 5500 | 5500 | 4000 | 8000 | 6000 | 4000 | 8000 |
| 10 | 5500 | 5500 | 0 | 0 | 0 | 0 | 0 |
| TOTAL | 44000 | 44000 | 4000 | 8000 | 6000 | 4000 | 8000 |

| STACK | E | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|
| FLOW l/min | 4.0 | 4.0 | 8.0 | 8.0 | 12.0 | 16.0 | 16.0 |
| Tray # | | | | | | | |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 13 | 6000 | 6000 | 4000 | 8000 | 6000 | 4000 | 8000 |
| 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| TOTAL | 6000 | 6000 | 4000 | 8000 | 6000 | 4000 | 8000 |

In Year II, eggs were fertilized on Oct. 26, 1977. Eyed eggs were pooled and distributed on Dec. 16, 1977, 417°C-days after fertilization. The average wet weight per egg was 490 mg (SD = 100 mg, coefficient of variation = 20%). It was estimated that 50% hatch occurred on Dec. 30, 1977, at 529°C-days. Fish were moved to rearing ponds on Feb. 21, 1978, at 949°C-days.

In Year I, monitoring continued for 45 days after ponding. During this period the fish were held in plywood rearing boxes (0.3 x 0.3 x 2.0 m) -- the front, back and bottom of these boxes consisted of polyester netting. Fish were ponded and fed Oregon Moist Pellet (OMP) Mash and then 1/32 inch OMP pellets. In Year II loading was limited to one tray per stack to provide optimal water quality for incubation. In both years selected fish and water quality parameters were monitored throughout the experiment.

## Fish Quality

The trays of alevins were subsampled weekly for length and weight measurements. If more than one tray in a stack contained eggs, the top and bottom trays were sampled. About 20 alevins were removed each time. After the measurements were taken, the alevins were preserved in 5% formalin for 48 hours and reweighed. Weekly mortality records were kept from hatching to ponding and in Year I also from ponding to day 46 following ponding. Dead fish were routinely removed.

## Water Quality

Water samples were routinely taken from the top and bottom egg containing trays of each Heath stack for oxygen, ammonia-N and pH determinations. Dissolved oxygen concentrations were determined using the azide modification of the Winkler method (APHA et al., 1975). Ammonia-N was measured using the indophenol blue plus sodium nitroprusside intensifier method (Zadorojny et al. 1973). The pH was determined using an Accumet digital pH/ion meter (Model 420). Water temperature was measured continuously using a Fisher and Porter temperature probe and strip chart recorder. Average weekly temperatures were calculated from these records.

## Ammonia-N Production and Oxygen Consumption Rate Calculations

Ammonia-N production rates "R" (mg ammonia-N/1000 alevins/hour) were calculated from:

$$R = \frac{(Ai - Ao)60Q}{nN/1000} \qquad (1)$$

where: R = ammonia nitrogen production rate (mg/1000 alevins/hr)
Q = water flow (l/min)
Ai = ammonia-N concentration at inflow (mg/l)
Ao = ammonia-N concentration at outflow (mg/l)
n = number of trays in stack
N = number of alevins per tray

The gross oxygen consumption rate "RG" (mg/1000 alevins/hr) was calculated using a similar procedure:

$$RG = \frac{(Ci - Co)60Q}{nN/1000} \qquad (2)$$

where: RG = gross oxygen consumption rate (mg/1000 alevins/hr)
Ci = oxygen concentration at inflow (mg/l)
Co = oxygen concentration at outflow (mg/l)

and: Q, n and N are defined in the expression for R

RG as calculated from equation (2) reflects not only the oxygen consumed by alevin respiration but also the effects of reaeration as the water falls from tray to tray. These effects can be separated if it is recognized that the net rate of change in the oxygen concentration (dC/dt) depends on the rate at which alevin metabolism decreases the oxygen concentration ($P'$) and on the rate of reaeration. Since the rate of oxygen uptake due to reaeration is proportional to the oxygen deficit (Cs - C):

$$dC/dt = k'(Cs - C) - P' \qquad (3)$$

where: $k'$ = reaeration coefficient ($time^{-1}$)
$P'$ = oxygen concentration decrease per unit time due to alevin respiration
Cs = oxygen concentration at 100% saturation (mg/l)

Equation (3) can be solved if initial conditions are defined. Let the oxygen concentration at the top of the stack be "Ci" -- this corresponds to the initial concentration (ie. at time = 0).

If the alevin oxygen uptake rate ($P'$) is constant throughout the stack (in other words the trays are loaded identically) then the oxygen concentration will depend on the contact time between the water and alevins. It should be noted that contact time is simply proportional to the number of trays the water has passed through. The oxygen concentration will also depend on the reaeration coefficient "$k'$". These relationships can be expressed quantitively by solving equation (3) for the oxygen concentration "C" as a function of the contact time "t":

$$C = Cs - P'/k' - (Cs - Ci - P'/k')\exp(-k't) \qquad (4)$$

It is convenient to replace the contact time "t" by "n" (the number of trays the water has travelled through). Furthermore, $k'$ and $P'$ can be expressed on a per tray basis; this gives:

$$Co = Cs - P/k - (Cs - Ci - P/k)\exp(-kn) \qquad (5)$$

where: n = the number of identically loaded trays
Co = oxygen concentration (mg/l) after passing through "n" trays

P = decrease in oxygen concentration per tray due to alevin respiration
k = reaeration coefficient ($tray^{-1}$)
Cs = oxygen concentration at 100% saturation (mg/l)
Ci = oxygen concentration at the stack inflow (mg/l)
exp = exponential; ie. $exp(a) = e^a$
e = 2.718...

The oxygen concentration decrease per tray due to alevin respiration (P) can be expressed in terms of the alevin metabolic rate. Metabolic rate (Ro) in units of mg of oxygen consumed per 1000 alevins per hour is related to P by:

$$Ro = \frac{PQ60}{N/1000} \qquad (6)$$

where: Ro = metabolic rate (oxygen consumption rate, mg/1000 alevins/hr)
P = decrease in oxygen concentration per tray due to alevin respiration
N = number of alevins per tray
Q = water flow (l/min)

This expression can be solved for P and substituted into equation (5) to obtain a general expression for the oxygen concentration at the outflow of the nth tray (Co):

$$Co = Cs - (Cs - Ci)exp(-kn) + \frac{RoN(exp(-kn) - 1)}{60,000Qk} \qquad (7)$$

where: symbols are the same as those given in equation 4, 5 and 6.

The alevin metabolic rate (Ro) can be found by rearranging equation (7):

$$Ro = \frac{Qk60,000(Co - Cs + (Cs - Ci)exp(-kn))}{N(exp(-kn) - 1)} \qquad (8)$$

This calculation of the alevin metabolic rate (Ro) from Heath stack information requires knowledge of the reaeration rate (k). It should be noted that Ro can easily be related to the gross oxygen consumption rate (RG) if it is assumed that the inflow oxygen concentration (Ci) is near the saturation concentration (Cs). This is usually the case in production hatcheries. If so, Ro can be related to RG by:

$$Ro = \frac{(RG)kn}{1 - exp(-kn)} \qquad (9)$$

## Measurement of the Reaeration Coefficient "k"

If the trays contain no alevins then N = 0 and equation 7 reduces to:

$$Co = Cs - (Cs - Ci)\exp(-kn) \qquad (10)$$

Equation 10 can be rearranged to give:

$$\ln(Cs - Co) = \ln(Cs - Ci) - kn \qquad (11)$$

Thus a plot of $\ln(Cs - Co)$ vs "n" should yield a straight line with a slope equal to the reaeration coefficient "k".

Nitrogen gas was used to scrub oxygen from the water to obtain initial oxygen concentrations varying between 3.1 and 9.7 mg/l. This water was then passed down the stack of trays and Co was measured after the third and seventh tray (n = 3 and n = 7). This information was substituted into equation 11 and the value of the reaeration coefficient was obtained from the slope of the least square line. These trials were carried out at a water temperature of 9.8°C and the oxygen saturation value was 11.31 mg/l. Water flow rates through the stack ranged between 12.9 and 16 liters/min.

## RESULTS

### Temperature Unit Data

The average temperature and accumulation of temperature units over the incubation period are shown for each experimental year in Appendix I and II. A summary of this information is given in Table 3.

Table 3. Summary of temperature unit data, for Year I and Year II experiments.

| Experimental Group | TU to 50% hatch (°C days) | Days to 50 % hatch | TU to Ponding (°C days) | Days to/after Ponding | Avg. (°C) | Temp SD |
|---|---|---|---|---|---|---|
| Year I (1977 Incubation) | 521 | 55 | 956 | 104 | 8.88* | 0.36 |
| Rearing | | | | 46 | 8.95 | 0.46 |
| Year II (1978 Incubation) | 529 | 65 | 949 | 118 | 7.94* | 0.40 |

* Avg. Temp. between hatch and ponding

### Fish Quality

After hatching, alevins gained weight rapidly until they approached their maximum weight. Exogenous feeding began near this time. After the initiation of feeding, it was noted that weight was essentially constant for about 11 days. If fish were not fed, weight loss occurred quickly. This general pattern is shown in Fig. 2 for Year I data. Mean fish length and weight data are given in Appendices III and IV. It should be noted that all length weight data presented in this report refers to live fish (ie. not preserved in formalin).

Figure 2 suggests that weight increased linearly with time for about the first 46 days after hatch:

$$w = mt + b \qquad (12)$$

where: $w$ = alevin weight (mg)
$m$ = least square slope (mg/day)
$t$ = time from hatch, days ($t \leq 46$, Year I data; $t \leq 47$, Year II data)
$b$ = intercept

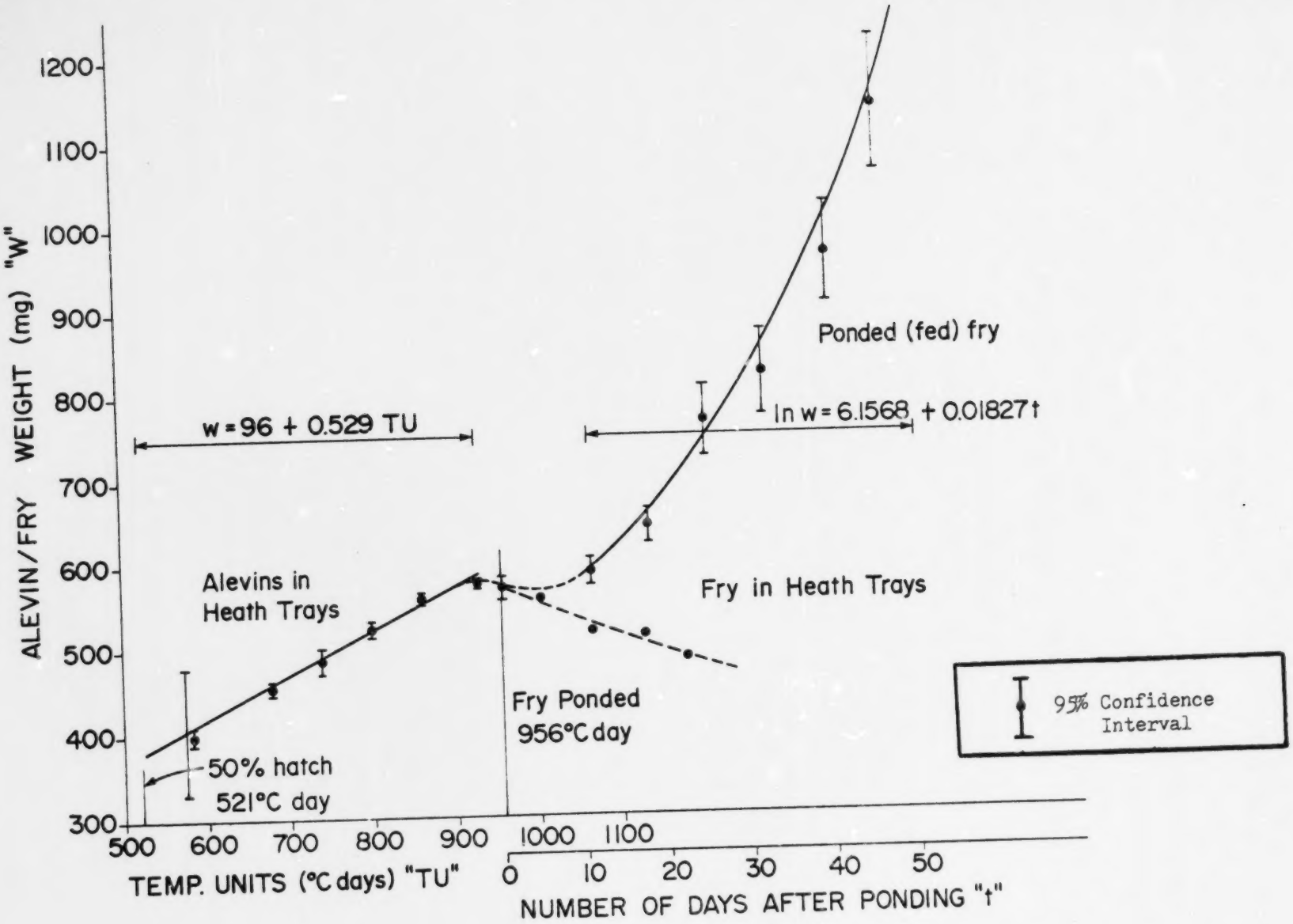


Figure 2: Average alevin/fry weights for samples taken during the period between 50% hatch and 45 days after ponding (year 1).

The slopes "m" (mg weight gained per day) were used for comparing experimental treatments. A larger weight gain per day was assumed to indicate a more favourable environment.

It was also noted (Fig. 2) that after effective feeding began (about 11 days after the initiation of feeding) that fry weight increased exponentially:

$$w = woe^{gt} \qquad (13)$$

or $$lnw = lnwo + gt$$

where: ln = natural logarithm
w = fry weight (mg)
t = time (days) ($11 \leq t \leq 46$)
g = least square slope of lnw vs. t
lnwo = intercept

The specific growth rate (or fractional weight gain per day) was estimated from the slope "g". Thus a slope of 0.018 was interpreted as a 1.8% gain in body weight per day. These values were used as an indicator of fry viability during the first forty-five days of rearing.

Regression equations for alevin weight vs. time (incubation) and the natural logarithm of fry weight vs. time (early rearing) are shown for the various experimental treatments in Table 4. In Year I, where tray densities ranged from 3005 to 7992 eggs/tray, stack loadings were below 24,000 eggs and stack flows were 12 l/min, the weight gain per day was remarkably constant between experimental treatments. The highest gain was 4.94 mg/day (4252 egg/tray) while the lowest weight gain was 4.44 mg/day (3005 and 6745 eggs/tray). Analysis of covariance was used to test differences ($\alpha = 0.05$ level) between slopes. It was concluded that weight gain per day was independent of initial egg density under the conditions of this experiment.

It was thought that differences between the various incubation environments might show up in early rearing. Unfortunately, experimental conditions during rearing are difficult to control with the result that measured values have considerable variability. Hence small differences between experimental treatments cannot be detected without intensive sampling and replication.

The lowest measured specific growth rate in early rearing was 1.56%/day (6745 eggs/tray) while the highest growth rate was 2.04%/day (3005 eggs/tray). Analysis of covariance ($\alpha = 0.05$) did not show significant differences between slopes. These data suggest that incubation densities ranging between 3005 and 7992 eggs/tray had no significant influence on subsequent growth rates in early rearing.

Year II studies involved a range of tray densities, stack loadings and stack flows. Two eight-tray stacks were loaded at normal production loadings of 5500 eggs/tray with flows of 12 l/min. This gave a total stack loading of 3667 eggs per l/min. It was suspected that alevins in the bottom trays would be exposed to lower oxygen and higher ammonia concentrations and hence might

show lower weight gains. In fact there was no significant difference between the daily weight gains of alevins in the top and bottom trays of the stacks where the weight gains respectively were 4.05 mg/day and 4.25 mg/day.

The range of treatments consisting of one tray per stack loaded at 4000, 6000 or 8000 eggs and operated at flows between 4 l/min and 16 l/min were also monitored for alevin weight. The individual regression lines are shown in Table 4. The greatest weight gain occurred in trays loaded at 4000 eggs and operated at a flow of 8 l/min (4.59 mg weight gain per day) while the lowest weight gain took place in trays loaded at 8000 eggs with a flow rate of 8 l/min (3.70 mg/day). Although differences between daily weight gains were not significant at the 0.05 level, significant differences between the lowest and highest treatments did exist at the 0.10 level.

It is possible that at very high alevin densities (8000 egg/tray), a low flow rate such as 8 l/min was not uniformly distributed over the alevin mass. Localized areas of low dissolved oxygen and high ammonia would result in poor yolk conversion and reduced alevin growth. This suggests that high densities and low flows could result in problems even though the total stack loading might be low (it should be noted that the total stack loading in this treatment was only 1000 eggs per l/min).

Regression equations for individual treatments were pooled to give relationships for Year I incubation and rearing (Fig.2) and Year II incubation (Fig.3).

Table 4. Linear regression relationships for alevin weight "w" (mg) vs time.

t = days from 50% hatch

Year I (Incubation; t < 46 days)

| Treatment Density (eggs/tray) | Flow (l/min) | Relationship | r | n |
|---|---|---|---|---|
| 3005 | 12 | w = 371 + 4.44 t | 0.9721 | 12 |
| 4252 | 12 | w = 359 + 4.94 t | 0.9776 | 12 |
| 5499 | 12 | w = 373 + 4.74 t | 0.9910 | 12 |
| 6745 | 12 | w = 377 + 4.44 t | 0.9851 | 12 |
| 7992 | 12 | w = 378 + 4.55 t | 0.9917 | 12 |

t = days from ponding

Year I (Rearing; 11 < t < 46 days)

| Treatment Density (eggs/tray) | Flow (l/min) | Relationship | r | n |
|---|---|---|---|---|
| 3005 | 12 | lnw = 6.1048 + 0.02036 t | 0.9659 | 12 |
| 4252 | 12 | lnw = 6.1711 + 0.01898 t | 0.9822 | 12 |
| 5499 | 12 | lnw = 6.2031 + 0.01642 t | 0.9119 | 12 |
| 6745 | 12 | lnw = 6.1869 + 0.01559 t | 0.9580 | 12 |
| 7992 | 12 | lnw = 6.1178 + 0.01998 t | 0.9493 | 12 |

t = days from 50% hatch

Year II (Incubation; t < 47 days)

| Treatment Density (eggs/tray) | Flow (l/min) | Relationship | r | n |
|---|---|---|---|---|
| 6000 | 4 | w = 402 + 4.27 t | 0.9736 | 8 |
| 4000 | 8 | w = 408 + 4.59 t | 0.9736 | 8 |
| 8000 | 8 | w = 423 + 3.70 t | 0.9562 | 8 |
| 6000 | 12 | w = 408 + 4.07 t | 0.9575 | 8 |
| 4000 | 16 | w = 424 + 3.97 t | 0.9791 | 8 |
| 8000 | 16 | w = 409 + 4.32 t | 0.9821 | 8 |
| Top Tray | | | | |
| 5500 | 12 | w = 418 + 4.05 t | 0.9859 | 8 |
| Bottom Tray | | | | |
| 5500 | 12 | w = 423 + 4.25 t | 0.9842 | 8 |

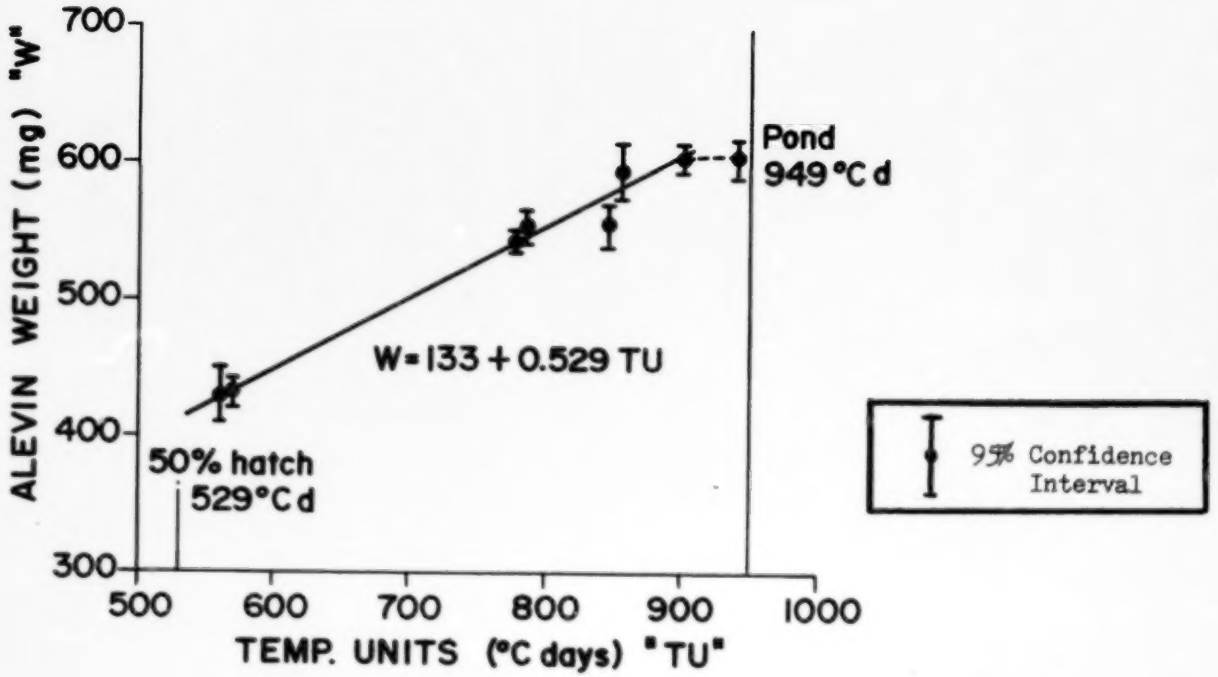


Figure 3: Average alevin weights for samples taken between 50% hatch and ponding vs. temperature units (T.U.) from fertilization (Year II).

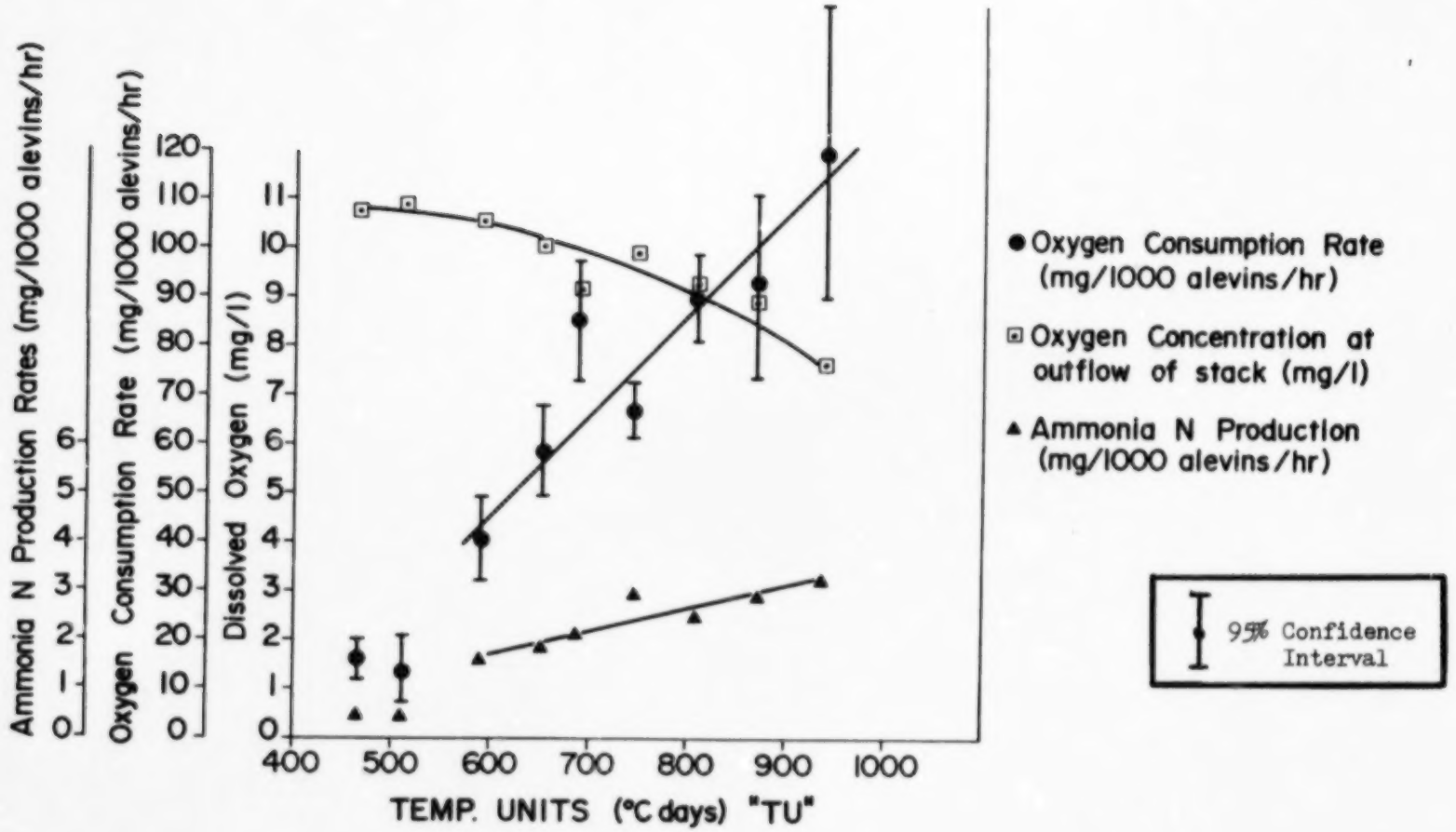


Figure 4: Average oxygen consumption and ammonia production rates and the average oxygen concentration at the stack outflows as a function of temperature units from fertilization. (Year I)

## Mortality

Table 5 summarizes alevin mortality for the various experimental treatments. Overall alevin mortality for Year I averaged 1.43% from hatch to ponding. Mortality differences between experimental treatments were small: mean rates ranged from 1.16% (4252 eggs/tray) to 1.64% (5499 eggs/tray). These differences were not significant and the rates were comparable to alevin mortalities experienced by production chinook at the Quinsam Hatchery that year (1.55%).

Mortality during the early rearing phase of the experiment (46 days) also was low. The average mortality rate was 1.18% (range 0.60 to 1.63%).

Overall alevin mortality during Year II averaged 0.77%. The high density, low flow treatments (D = 8000, Q = 8 l/min) experienced the highest mean mortality (1.31%). Although this was an acceptable rate, it was significantly higher than the mortalities experienced in the other treatments.

## Water Quality

The Year I experiment involved a maximum alevin loading of 24,000 alevins per 12 l/min of inflow. This loading provided sufficient oxygen/ammonia concentration changes so that rate of oxygen consumption and ammonia production could be measured accurately (Tables 6 and 7). In addition, loadings were light enough that acceptable water quality was maintained throughout the stack. Over the alevin incubation period, the oxygen concentration in the bottom trays averaged 9.7 mg/l while the lowest measured oxygen value was 7.2 mg/l. The highest measured ammonia-N concentration was 120 ug/l. This resulted in an un-ionized ammonia-N concentration of 0.4 ug/l (temperature = 9.7°C, pH = 7.28)(Fig.4). A sampling of the water quality data collected during the study is presented in Appendix V.

Heath stacks loaded at production levels were monitored in Year II. Two stacks were loaded at 44,000 alevins per 12 l/min of inflow (5500 alevins per tray). The oxygen concentration in the bottom trays averaged 7.93 mg/l while the lowest measured value was 6.1 mg/l. The highest un-ionized ammonia-N concentration was 0.4 ug/l. These metabolite concentrations had no effect on the alevin weight gain. As was mentioned previously there was no significant difference between the daily weight gains of alevins in the top and bottom trays of the stacks.

Eleven independent tests were carried out to determine the reaeration coefficient "k". In each test the oxygen concentration was measured before the first tray (n = 0) and at the 3rd and 7th trays. Thus 3 values were obtained for each trial. The slope was obtained from least square regression analysis. The mean slope for the 11 trials and the 95% confidence interval was:

$$k = 0.0555 \pm 0.0086$$

This was taken as the best estimate of the reaeration coefficient, k.

Oxygen consumption and ammonia production rates increased as the alevins developed (Tables 7 and 8). Significant differences could not be detected between experimental treatments so the data were pooled. Linear regression was used to express "rate values" as a function of temperature units (Table 8). The pooled relationships for Year I are:

$$Ro = -65.4 + 0.192\ (TU), \quad r = 0.8329, \ n = 35 \qquad (14)$$

$$R = -1.094 + 0.0047\ (TU), \quad r = 0.8328, \ n = 35 \qquad (15)$$

$$\text{and } 591 \leq TU \leq 937$$

where:

Ro = mean alevin oxygen consumption rate (mg/1000 eggs/hr)
R = alevin ammonia-N (mg/1000 eggs/hr)
TU = temp. units, $^{o}C$ days
r = correlation coefficient
n = number of pairs of measurements involved in regression line.

It should be noted that the average temperature over these measurements was 8.9°C. Also, the oxygen uptake rates, Ro, were independent of the Heath stack reaeration effects.

Carbon dioxide production rates would increase with alevin development. This was undoubtedly the cause of the decrease in pH of water passing through the loaded Heath stacks. The magnitude of the pH drop ($\Delta$ pH) was strongly correlated with the magnitude of the oxygen concentration drop ($\Delta$ DO):

$$\Delta pH = 0.061 + 0.110(\Delta DO), \quad n = 61, \ r = 0.7062 \qquad (16)$$

where: $\Delta pH$ = pH decrease
$\Delta DO$ = oxygen concentration decrease
r = correlation coefficient
n = pairs of measurements.

Table 5. Total mortality (%) for the various experimental treatments. The rearing mortality was monitored for the 45-day period following ponding in Year I. Incubation mortality includes the period between hatch and ponding.

Year I (1976 Brood)

| Treatment | | | Incubation Mort. (%) | | Rearing Mort. (%) | |
|---|---|---|---|---|---|---|
| Flow | Density | Tray No. | Per Tray | Mean | Per Tray | Mean |
| 12 | 3005 | A3 | 1.93 | 1.50 | 1.30 | 1.37 |
| 12 | 3005 | A10 | 1.06 | | 1.43 | |
| 12 | 4252 | B3 | 1.36 | 1.16 | 1.49 | 1.63 |
| 12 | 4252 | B7 | 0.96 | | 1.77 | |
| 12 | 5499 | C3 | 1.69 | 1.64 | 1.32 | 1.10 |
| 12 | 5499 | C6 | 1.58 | | 0.88 | |
| 12 | 6745 | D3 | 1.69 | 1.59 | 0.86 | 0.60 |
| 12 | 6745 | D5 | 1.48 | | 0.33 | |
| 12 | 7992 | E3 | 1.48 | 1.26 | 1.32 | 1.23 |
| 12 | 7992 | E5 | 1.04 | | 1.14 | |

Year II (1977 Brood)

| Treatment | | | Incubation Mortality (%) | |
|---|---|---|---|---|
| Flow | Density | Tray No. | Per Tray | Mean |
| 12 | 5500 | C3 | 0.53 | 0.61 |
| 12 | 5500 | C10 | 0.67 | |
| 12 | 5500 | D3 | 0.56 | |
| 12 | 5500 | D10 | 0.67 | |
| 8 | 4000 | E9 | 0.42 | 0.54 |
| 8 | 4000 | G13 | 0.65 | |
| 8 | 8000 | F9 | 1.22 | 1.31 |
| 8 | 8000 | H13 | 1.40 | |
| 12 | 6000 | G9 | 0.67 | 0.77 |
| 12 | 6000 | I13 | 0.87 | |
| 16 | 4000 | H9 | 0.53 | 0.55 |
| 16 | 4000 | J13 | 0.56 | |
| 16 | 8000 | I9 | 0.87 | 0.90 |
| 16 | 8000 | K13 | 0.93 | |
| 4 | 6000 | E13 | 0.78 | 0.88 |
| 4 | 6000 | F13 | 0.98 | |

Table 6. Oxygen consumption rates (mg/1000 alevins/hr) for individual egg density treatments in Year I and for stacks C and D in Year II.

Year I

| Sample Date | Dec 17/76 | Dec 22 | Dec 31 | Jan 7/77 | Jan 11 | Jan 18 | Jan 25 | Feb 1 | Feb 8 |
|---|---|---|---|---|---|---|---|---|---|
| Temp. °C | 9.8 | 9.5 | 8.5 | 8.7 | 8.9 | 9.2 | 8.3 | 9.2 | 9.7 |
| TU °C Days | 466 | 512 | 591 | 652 | 686 | 747 | 809 | 870 | 937 |
| Treatments | | | | | | | | | |
| A (3005/tray) | 12.9 | 4.5 | 50.5 | 58.9 | 74.5 | 63.0 | 96.3 | 114.5 | 123.1 |
| B (4252/tray) | 14.4 | 15.0 | 45.3 | 63.4 | 90.5 | 66.9 | 92.0 | 97.8 | 147.1 |
| C (5499/tray) | 19.4 | 18.3 | 34.1 | 68.8 | 98.6 | 64.0 | 95.8 | 91.6 | 135.4 |
| D (6745/tray) | 13.8 | 17.0 | 38.5 | 55.4 | 86.7 | 74.6 | 80.0 | 73.0 | 89.5 |
| E (7992/tray) | 20.4 | 16.1 | 36.6 | 48.4 | 76.4 | 67.1 | 88.9 | 86.3 | 103.0 |
| Mean | 16.2 | 14.2 | 41.0 | 59.0 | 85.3 | 67.1 | 90.6 | 92.6 | 119.6 |
| SD | 3.46 | 5.54 | 6.74 | 7.76 | 10.02 | 4.55 | 6.65 | 15.26 | 23.45 |

Year II

| Sample Date | Jan 10/78 | Jan 27 | Feb 1 | Feb 3 | Feb 7 | Feb 10 | Feb 13 | Feb 20 |
|---|---|---|---|---|---|---|---|---|
| Temp. °C | 8.4 | 7.8 | 7.9 | 8.1 | 6.8 | 7.4 | 8.0 | 8.2 |
| TU °C Days | 616 | 751 | 792 | 808 | 839 | 860 | 883 | 940 |
| Treatments | | | | | | | | |
| C (5500/tray) | 41.7 | 58.8 | 96.3 | 64.5 | 68.7 | 93.7 | 69.2 | 94.5 |
| D (5500/tray) | 40.7 | 55.7 | 81.2 | 78.9 | 79.3 | 96.1 | 87.7 | 108.4 |
| Mean | 41.2 | 57.3 | 88.8 | 71.7 | 74.0 | 94.9 | 78.5 | 101.5 |

Table 7. Ammonia-N production rates (mg/1000 alevins/hr) for individual egg density treatments in Year I and for stacks C and D in Year II.

Year I

| Sample Date | Dec 17/76 | Dec 22 | Dec 31 | Jan 7/77 | Jan 11 | Jan 18 | Jan 25 | Feb 1 | Feb 8 |
|---|---|---|---|---|---|---|---|---|---|
| Temp. °C | 9.8 | 9.5 | 8.5 | 8.7 | 8.9 | 9.2 | 8.3 | 9.2 | 9.7 |
| TU °C Days | 466 | 512 | 591 | 652 | 686 | 747 | 809 | 870 | 937 |
| Treatments | | | | | | | | | |
| A (3005/tray) | 0.39 | 0.40 | 1.60 | 1.82 | 2.01 | 2.97 | 2.47 | 3.08 | 3.57 |
| B (4252/tray) | 0.39 | 0.42 | 1.57 | 1.83 | 2.24 | 2.56 | 2.33 | 2.88 | 4.19 |
| C (5499/tray) | 0.40 | 0.43 | 1.41 | 1.93 | 2.10 | 3.22 | 2.70 | 2.93 | 2.39 |
| D (6745/tray) | 0.55 | 0.42 | 1.50 | 1.83 | 2.35 | 3.11 | 2.50 | 2.73 | 2.79 |
| E (7992/tray) | 0.61 | 0.42 | 1.54 | 1.90 | 1.92 | 2.89 | 2.41 | 3.10 | 3.12 |
| Mean | 0.47 | 0.42 | 1.52 | 1.86 | 2.12 | 2.95 | 2.48 | 2.94 | 3.21 |
| SD | 0.10 | 0.01 | 0.07 | 0.05 | 0.17 | 0.25 | 0.14 | 0.15 | 0.70 |

Year II

| Sample Date | Jan 10/78 | Jan 27 | Feb 1 | Feb 3 | Feb 7 | Feb 10 | Feb 13 | Feb 20 |
|---|---|---|---|---|---|---|---|---|
| Temp. °C | 8.4 | 7.8 | 7.9 | 8.1 | 6.8 | 7.4 | 8.0 | 8.2 |
| TU °C Days | 616 | 751 | 792 | 808 | 839 | 860 | 883 | 940 |
| Treatments | | | | | | | | |
| C (5500/tray) | 1.07 | 1.79 | 2.74 | 2.13 | 2.39 | 2.99 | 2.26 | 2.30 |
| D (5500/tray) | 0.92 | 1.73 | 2.94 | 2.13 | 2.88 | 2.96 | 2.55 | 2.86 |
| Mean | 1.00 | 1.76 | 2.84 | 2.13 | 2.64 | 2.98 | 2.41 | 2.58 |

Table 8. Linear regression relationships for the oxygen consumption rate Ro (mg/1000/hr) and ammonia-N production rate R (mg/1000/hr) vs temperature units from fertilization (TU).

Year I (Incubation)

| Treatment Density (per tray) | Flow (l/min) | Relationship | r | n |
|---|---|---|---|---|
| 3005 | 12 | Ro = -83.7 + 0.221 TU | 0.9546 | 7 |
| | | R = -1.69 + 0.0055 TU | 0.9354 | 7 |
| 4252 | 12 | Ro = -92.5 + 0.236 TU | 0.8893 | 7 |
| | | R = -2.28 + 0.0063 TU | 0.9136 | 7 |
| 5499 | 12 | Ro = -79.1 + 0.216 TU | 0.8309 | 7 |
| | | R = -0.10 + .0033 TU | 0.6511 | 7 |
| 6745 | 12 | Ro = -10.7 + 0.108 TU | 0.7350 | 7 |
| | | R = -0.23 + 0.0035 TU | 0.7618 | 7 |
| 7992 | 12 | Ro = -61.1 + 0.177 TU | 0.9298 | 7 |
| | | R = -1.17 + 0.0047 TU | 0.9126 | 7 |
| | | (591 < TU < 937) | | |

Year II (Incubation)

| Treatment Density (per tray) | Flow (l/min) | Relationship | r | n |
|---|---|---|---|---|
| 5500 | 12 | Ro = -69.4 + 0.179 TU | 0.8420 | 16 |
| | | R = -2.1 + 0.0054 TU | 0.7895 | 16 |
| | | (616 < TU < 940) | | |

## DISCUSSION

The lack of statistically significant effects of egg density on alevin viability intuitively is unexpected. With the range of densities tested in Year I there did not appear to be differences in mortality or growth rates during incubation or early rearing (Table 4 and 5). One simple explanation is that the range of densities tested was not wide enough to detect effects which obviously must exist. However, the range of densities used, 3000 to 8000 eggs per tray, was chosen for definite reasons. The lower density is the lowest economically feasible number and the upper one is the limit imposed by the physical size of the chinook eggs. Therefore, the issue of effects above or below the range tested is of no practical consequence.

It should be pointed out that in both years the numbers of eggs per stack were generally maintained at a very low level. In Year I, although individual trays held up to 8000 eggs, the maximum "stack loading" was only 24,000 eggs or 2000 eggs per liter/min of water flow. Thus, in all treatments water quality was maintained at a very high level throughout incubation. The oxygen levels at the tray outflows were above 10.7 mg/l (95% of saturation) near hatch and above 7 mg/l at ponding. Furthermore, un-ionized ammonia levels were below 0.4 ug/l at all times. It was intended that the low stack loads would result in near ideal water quality and hence make the effects of tray density alone more evident.

It was originally thought that the higher densities might provide some of the benefits of an incubation substrate. Thus it was hypothesized that the higher density trays might produce larger more viable fry at ponding. Emadi(1973) has pointed out that chinook and coho, unlike pink, chum and sockeye alevins, did not seem to need a substrate for successful incubation. It was observed that chinook and coho were not susceptible to yolk-sac malformation when provided with smooth walled high velocity incubators lacking substrate. Emadi's observation with chinook is supported by the present work if it is assumed that increased tray density is equivalent to the addition of an external substrate. However, it should be emphasized that alevins were not examined closely for yolk-sac malformation nor was an external substrate tested. Alevin viability was assessed solely on the basis of growth and mortality rates during incubation and early rearing.

Since substrate provides benefits in the incubation of chum, pink and sockeye salmon and with steelhead trout (McLean and Wolfe, unpubl. data. Robertson Creek Hatchery, Port Alberni, B.C.) the possible benefits to chinook and coho should be examined more closely in a production hatchery setting. These studies must focus on more subtle indicators of alevin viability than mortality and growth rates. They must characterize the incidence of yolk-sac malformation during incubation and also strive to identify related disease problems in early rearing (eg. fin rot).

In Year II of the study a wide range of both water flow rates and egg densities were tested. Also, a typical production

stack consisting of 8 trays loaded at 5500 eggs per tray with a water flow rate of 12 liters/min was monitored. An indication that there are indeed negative effects of high density and low flow is suggested by the results of the single tray stack loaded at 8000 eggs per tray and operated at 8 liters /min. This was the only treatment that showed elevated mortality and reduced weight gain. It is hypothesized that localized areas of low oxygen and high ammonia existed within the trays and contributed to the overall poor performance.

It is of interest to note with this treatment, that simply monitoring the tray outflow would not have demonstrated the hypothesized decrease in water quality. Outflow water quality only reflects average conditions within the tray -- localized areas of low dissolved oxygen or high ammonia are not detectable with the water monitoring programs usually carried out at hatcheries. It is common practice to report acceptable outflow conditions when in fact intense areas of low dissolved oxygen exist within an incubator (Britton et. al., 1983).

The stacks loaded at typical production levels (8 trays at 5500 eggs per tray) showed no difference in mortality or growth rate between the top and bottom trays. This indicated that the water flow rate of 12 liters per minute provided sufficient oxygen to meet the needs of all trays (including the bottom tray). The lowest measured oxygen concentration occurred just prior to ponding (Appendix V) -- this level met the water quality criteria proposed for hatchery operation by Sigma (1983).

It is clear from the results of these experiments that there exists an optimal ponding time. Monitoring of the growth trend of alevins in Year I showed that ponding at 956°C-days actually occurred after maximum alevin wet weight had been attained. Feeding at this time resulted in an eleven day period when alevin weight remained constant or decreased slightly. Heming et. al (1982) recommend initiation of feeding just prior to maximum alevin wet weight in order to minimize this pause and encourage continuous growth. Ideally feeding should have begun at 923°C-days.

These experiments established the framework for a model which predicts ammonia or oxygen concentrations at the outflow of the nth tray in a Heath stack. Equation (7) predicts the oxygen concentration after n trays as a function of: the number of alevins per tray (N), oxygen concentration at the inflow of the stack (Ci), oxygen saturation concentration (Cs), reaeration coefficient (k), water flow rate (Q) and the metabolic rate (Ro). The metabolic rate is a function of water temperature, life stage and species. Hence the present work is of limited predictive value because it involves only post hatch chinook at intermediate water temperatures (8 - 9°C). Work now in progress to model Ro for a variety of species over a wide range of temperatures (Rombough, MS), should allow the development of a very useful incubation model.

Using the information currently available, the model predicts that for a normal eight-tray Heath stack loaded at 5500 alevins per tray the oxygen concentration would be 1.3 mg/l higher at the outflow of the eighth tray than in a stack where negligible reaeration occurred between trays. However, even with the

reaeration effect operating, oxygen levels in the eighth tray would have fallen to 6 mg/l. Increasing reaeration between trays would be advantageous and may be possible with simple modifications to the normal Heath stack. These projections were made for chinook using equation (7) under the following conditions: TU = 920°C days, Ro = 111 mg/1000/hr (eq. 14), T = 9°C, Cs = 11.5 mg/l, Ci = 11.5 mg/l, k = 0.055 per tray, N = 5500 alevins and n = 8 trays.

In summary, the value of this work was threefold. First, there was no statistical evidence that egg density, within a realistic or practical range, affects the growth or mortality rates of chinook salmon eggs incubated in Heath trays. Although it would appear logical to reduce alevin activity through increased density or decreased flow, data from the current experiments does not support this view. Secondly, data from these experiments illustrate the importance of ponding alevins at the proper time. Normally, there may be a latent period when the transition is made between endogenous and exogenous feeding. That is, there may be a natural pause in growth after ponding as the alevin learns to feed on externally presented food. The 11 day period of no growth following ponding likely is an extension of this latent period as external feeding was initiated after, rather than before maximum alevin wet weight had been attained. Thirdly, a framework has been established for a general incubation model. This model can be used to predict water quality parameters for any tray in a Heath stack. Alternatively, it could be used to predict allowable tray loadings or minimum water flow requirements to maintain a specified level of environmental quality within a Heath stack.

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Appendix I: Average daily temperature and accumulated temperature units from fertilization (day 0) for the incubation of 1976 brood chinook (Year I).

* Dec. 23, 1976 = 50 % hatch

| Date | Day | Temp °C | Accum Temp | Date | Day | Temp °C | Accum Temp |
|---|---|---|---|---|---|---|---|
| 29/10/76 | 0 | 9.9 | - | 05/12/76 | 37 | 9.1 | 351.1 |
| 30/10/76 | 1 | 9.9 | 9.9 | 06/12/76 | 38 | 9.2 | 360.3 |
| 31/10/76 | 2 | 10.0 | 19.9 | 07/12/76 | 39 | 9.5 | 369.8 |
| 01/11/76 | 3 | 9.7 | 29.6 | 08/12/76 | 40 | 9.4 | 379.2 |
| 02/11/76 | 4 | 9.6 | 39.2 | 09/12/76 | 41 | 9.2 | 388.4 |
| 03/11/76 | 5 | 9.8 | 49.0 | 10/12/76 | 42 | 9.5 | 397.9 |
| 04/11/76 | 6 | 9.8 | 58.8 | 11/12/76 | 43 | 9.5 | 407.4 |
| 05/11/76 | 7 | 9.8 | 68.6 | 12/12/76 | 44 | 9.6 | 417.0 |
| 06/11/76 | 8 | 9.9 | 78.5 | 13/12/76 | 45 | 9.5 | 426.5 |
| 07/11/76 | 9 | 10.1 | 88.6 | 14/12/76 | 46 | 9.7 | 436.2 |
| 08/11/76 | 10 | 10.2 | 98.8 | 15/12/76 | 47 | 9.8 | 446.0 |
| 09/11/76 | 11 | 10.3 | 109.1 | 16/12/76 | 48 | 10.0 | 456.0 |
| 10/11/76 | 12 | 10.1 | 119.2 | 17/12/76 | 49 | 9.8 | 465.8 |
| 11/11/76 | 13 | 9.8 | 129.0 | 18/12/76 | 50 | 9.2 | 475.0 |
| 12/11/76 | 14 | 9.7 | 138.7 | 19/12/76 | 51 | 9.0 | 484.0 |
| 13/11/76 | 15 | 9.6 | 148.3 | 20/12/76 | 52 | 9.2 | 493.2 |
| 14/11/76 | 16 | 9.8 | 158.1 | 21/12/76 | 53 | 9.1 | 502.3 |
| 15/11/76 | 17 | 9.7 | 167.8 | 22/12/76 | 54 | 9.5 | 511.8 |
| 16/11/76 | 18 | 9.8 | 177.6 | 23/12/76 | 55 | 9.1 | *520.9 |
| 17/11/76 | 19 | 9.6 | 187.2 | 24/12/76 | 56 | 8.9 | 529.8 |
| 18/11/76 | 20 | 9.6 | 196.8 | 25/12/76 | 57 | 8.8 | 538.6 |
| 19/11/76 | 21 | 9.5 | 206.3 | 26/12/76 | 58 | 8.5 | 547.1 |
| 20/11/76 | 22 | 9.2 | 215.5 | 27/12/76 | 59 | 8.5 | 555.6 |
| 21/11/76 | 23 | 9.4 | 224.9 | 28/12/76 | 60 | 8.9 | 564.5 |
| 22/11/76 | 24 | 9.4 | 234.3 | 29/12/76 | 61 | 9.1 | 573.6 |
| 23/11/76 | 25 | 9.6 | 243.9 | 30/12/76 | 62 | 8.8 | 582.4 |
| 24/11/76 | 26 | 9.5 | 253.4 | 31/12/76 | 63 | 8.6 | 591.0 |
| 25/11/76 | 27 | 9.1 | 262.4 | 01/01/77 | 64 | 8.8 | 599.8 |
| 26/11/76 | 28 | 8.9 | 271.4 | 02/01/77 | 65 | 8.8 | 608.6 |
| 27/11/76 | 29 | 8.8 | 280.2 | 03/01/77 | 66 | 8.7 | 617.3 |
| 28/11/76 | 30 | 8.7 | 288.9 | 04/01/77 | 67 | 8.5 | -625.8 |
| 29/11/76 | 31 | 8.7 | 297.6 | 05/01/77 | 68 | 8.6 | 634.4 |
| 30/11/76 | 32 | 8.7 | 306.3 | 06/01/77 | 69 | 8.7 | 643.1 |
| 01/12/76 | 33 | 8.8 | 315.1 | 07/01/77 | 70 | 8.6 | 651.7 |
| 02/12/76 | 34 | 8.8 | 323.9 | 08/01/77 | 71 | 8.4 | 660.1 |
| 03/12/76 | 35 | 9.1 | 333.0 | 09/01/77 | 72 | 8.8 | 668.9 |
| 04/12/76 | 36 | 9.0 | 342.0 | 10/01/77 | 73 | 8.7 | 677.6 |

Appendix I cont'd

| Date | Day | Temp °C | Accum Temp | Date | Day | Temp °C | Accum Temp |
|---|---|---|---|---|---|---|---|
| 11/01/77 | 74 | 8.6 | 686.2 | 19/02/77 | 113 | 9.3 | 1039.9 |
| 12/01/77 | 75 | 8.7 | 694.9 | 20/02/77 | 114 | 9.4 | 1049.3 |
| 13/01/77 | 76 | 8.8 | 703.7 | 21/02/77 | 115 | 9.2 | 1058.5 |
| 14/01/77 | 77 | 8.5 | 712.2 | 22/02/77 | 116 | 8.7 | 1067.2 |
| 15/01/77 | 78 | 8.5 | 720.7 | 23/02/77 | 117 | 8.5 | 1075.7 |
| 16/01/77 | 79 | 8.9 | 729.6 | 24/02/77 | 118 | 8.7 | 1084.4 |
| 17/01/77 | 80 | 8.8 | 738.4 | 25/02/77 | 119 | 8.7 | 1093.1 |
| 18/01/77 | 81 | 9.0 | 747.4 | 26/02/77 | 120 | 8.7 | 1101.8 |
| 19/01/77 | 82 | 8.9 | 756.3 | 27/02/77 | 121 | 8.9 | 1110.7 |
| 20/01/77 | 83 | 9.1 | 765.4 | 28/02/77 | 122 | 9.0 | 1119.7 |
| 21/01/77 | 84 | 9.0 | 774.4 | 01/03/77 | 123 | 8.8 | 1128.5 |
| 22/01/77 | 85 | 8.8 | 783.2 | 02/03/77 | 124 | 8.3 | 1136.8 |
| 23/01/77 | 86 | 8.7 | 791.9 | 03/03/77 | 125 | 8.3 | 1145.1 |
| 24/01/77 | 87 | 8.6 | 800.5 | 04/03/77 | 126 | 8.8 | 1153.9 |
| 25/01/77 | 88 | 8.6 | 809.1 | 05/03/77 | 127 | 9.0 | 1162.9 |
| 26/01/77 | 89 | 8.5 | 817.6 | 06/03/77 | 128 | 8.9 | 1171.8 |
| 27/01/77 | 90 | 8.5 | 826.1 | 07/03/77 | 129 | 8.5 | 1180.3 |
| 28/01/77 | 91 | 8.5 | 834.6 | 08/03/77 | 130 | 7.8 | 1188.1 |
| 29/01/77 | 92 | 8.8 | 843.4 | 09/03/77 | 131 | 7.7 | 1195.8 |
| 30/01/77 | 93 | 8.9 | 852.3 | 10/03/77 | 132 | 8.2 | 1204.0 |
| 31/01/77 | 94 | 8.9 | 861.2 | 11/03/77 | 133 | 8.6 | 1212.6 |
| 01/02/77 | 95 | 9.0 | 870.2 | 12/03/77 | 134 | 8.6 | 1221.2 |
| 02/02/77 | 96 | 9.2 | 879.4 | 13/03/77 | 135 | 8.7 | 1229.9 |
| 03/02/77 | 97 | 9.4 | 888.8 | 14/03/77 | 136 | 8.5 | 1238.4 |
| 04/02/77 | 98 | 9.3 | 898.1 | 15/03/77 | 137 | 8.8 | 1247.2 |
| 05/02/77 | 99 | 9.5 | 907.6 | 16/03/77 | 138 | 8.8 | 1256.0 |
| 06/02/77 | 100 | 9.5 | 917.1 | 17/03/77 | 139 | 9.1 | 1265.1 |
| 07/02/77 | 101 | 9.7 | 926.8 | 18/03/77 | 140 | 9.2 | 1274.3 |
| 08/02/77 | 102 | 9.9 | 936.7 | 19/03/77 | 141 | 9.3 | 1283.6 |
| 09/02/77 | 103 | 9.8 | 946.5 | 20/03/77 | 142 | 9.1 | 1292.7 |
| 10/02/77 | 104 | 9.4 | 955.9 | 21/03/77 | 143 | 9.6 | 1302.3 |
| 11/02/77 | 105 | 9.4 | 965.3 | 22/03/77 | 144 | 9.5 | 1311.8 |
| 12/02/77 | 106 | 9.3 | 974.6 | 23/03/77 | 145 | 9.5 | 1321.3 |
| 13/02/77 | 107 | 9.2 | 983.8 | 24/03/77 | 146 | 9.3 | 1330.6 |
| 14/02/77 | 108 | 9.0 | 992.8 | 25/03/77 | 147 | 9.1 | 1339.7 |
| 15/02/77 | 109 | 9.1 | 1001.9 | 26/03/77 | 148 | 9.3 | 1349.0 |
| 16/02/77 | 110 | 9.6 | 1011.5 | 27/03/77 | 149 | 9.3 | 1358.3 |
| 17/02/77 | 111 | 9.6 | 1021.1 | 28/03/77 | 150 | 9.5 | 1367.8 |
| 18/02/77 | 112 | 9.5 | 1030.6 | | | | |

Appendix II: Average daily temperature and accumulated temperature units from fertilization (day 0) for the incubation of 1977 brood chinook (Year II).

* Dec. 30, 1977 = 50 % hatch

| Date | Day | Temp °C | Accum Temp | Date | Day | Temp °C | Accum Temp |
|---|---|---|---|---|---|---|---|
| 26/10/77 | 0 | 9.5 | - | 01/12/77 | 36 | 7.5 | 306.2 |
| 27/10/77 | 1 | 9.7 | 9.7 | 02/12/77 | 37 | 7.6 | 131.8 |
| 28/10/77 | 2 | 9.6 | 19.3 | 03/12/77 | 38 | 8.0 | 321.8 |
| 29/10/77 | 3 | 9.6 | 28.9 | 04/12/77 | 39 | 7.9 | 329.7 |
| 30/10/77 | 4 | 9.5 | 38.4 | 05/12/77 | 40 | 7.2 | 336.9 |
| 31/10/77 | 5 | 9.3 | 47.7 | 06/12/77 | 41 | 7.3 | 344.2 |
| 01/11/77 | 6 | 8.9 | 56.6 | 07/12/77 | 42 | 7.7 | 351.9 |
| 02/11/77 | 7 | 9.0 | 65.6 | 08/12/77 | 43 | 7.8 | 359.7 |
| 03/11/77 | 8 | 9.0 | 74.6 | 09/12/77 | 44 | 7.3 | 367.0 |
| 04/11/77 | 9 | 9.0 | 83.6 | 10/12/77 | 45 | 7.4 | 374.4 |
| 05/11/77 | 10 | 9.2 | 92.8 | 11/12/77 | 46 | 7.0 | 381.4 |
| 06/11/77 | 11 | 8.9 | 101.7 | 12/12/77 | 47 | 7.3 | 388.7 |
| 07/11/77 | 12 | 8.7 | 110.4 | 13/12/77 | 48 | 6.6 | 395.3 |
| 08/11/77 | 13 | 8.4 | 118.8 | 14/12/77 | 49 | 6.8 | 402.1 |
| 09/11/77 | 14 | 8.1 | 126.9 | 15/12/77 | 50 | 7.2 | 409.3 |
| 10/11/77 | 15 | 8.7 | 135.6 | 16/12/77 | 51 | 7.2 | 416.5 |
| 11/11/77 | 16 | 9.2 | 144.8 | 17/12/77 | 52 | 7.6 | 424.1 |
| 12/11/77 | 17 | 8.7 | 153.5 | 18/12/77 | 53 | 7.9 | 432.0 |
| 13/11/77 | 18 | 8.5 | 162.0 | 19/12/77 | 54 | 8.1 | 440.1 |
| 14/11/77 | 19 | 8.3 | 170.3 | 20/12/77 | 55 | 8.2 | 448.3 |
| 15/11/77 | 20 | 8.4 | 178.7 | 21/12/77 | 56 | 8.1 | 456.4 |
| 16/11/77 | 21 | 8.5 | 187.2 | 22/12/77 | 57 | 8.1 | 464.5 |
| 17/11/77 | 22 | 8.3 | 195.5 | 23/12/77 | 58 | 8.0 | 472.5 |
| 18/11/77 | 23 | 8.0 | 203.5 | 24/12/77 | 59 | 7.9 | 480.4 |
| 19/11/77 | 24 | 7.9 | 211.4 | 25/12/77 | 60 | 7.8 | 488.2 |
| 20/11/77 | 25 | 8.2 | 219.6 | 26/12/77 | 61 | 7.8 | 496.0 |
| 21/11/77 | 26 | 8.1 | 227.7 | 27/12/77 | 62 | 7.9 | 503.9 |
| 22/11/77 | 27 | 8.0 | 235.7 | 28/12/77 | 63 | 8.1 | 512.0 |
| 23/11/77 | 28 | 7.3 | 243.0 | 29/12/77 | 64 | 8.5 | 520.5 |
| 24/11/77 | 29 | 8.1 | 251.1 | 30/12/77 | 65 | 8.4 | *528.9 |
| 25/11/77 | 30 | 7.9 | 259.0 | 31/12/77 | 66 | 8.3 | 537.2 |
| 26/11/77 | 31 | 7.6 | 266.6 | 01/01/78 | 67 | 8.0 | 545.2 |
| 27/11/77 | 32 | 7.9 | 274.5 | 02/01/78 | 68 | 7.9 | 553.1 |
| 28/11/77 | 33 | 8.0 | 282.5 | 03/01/78 | 69 | 7.7 | 560.8 |
| 29/11/77 | 34 | 8.0 | 290.5 | 04/01/78 | 70 | 7.2 | 568.0 |
| 30/11/77 | 35 | 8.2 | 298.7 | 05/01/78 | 71 | 7.4 | 575.4 |

Appendix II cont'd

| Date | Day | Temp °C | Accum Temp | Date | Day | Temp °C | Accum Temp |
|---|---|---|---|---|---|---|---|
| 06/01/78 | 72 | 8.0 | 583.4 | 11/02/78 | 108 | 7.5 | 867.4 |
| 07/01/78 | 73 | 7.8 | 591.2 | 12/02/78 | 109 | 7.7 | 875.1 |
| 08/01/78 | 74 | 8.2 | 599.4 | 13/02/78 | 110 | 8.0 | 883.1 |
| 09/01/78 | 75 | 8.3 | 607.7 | 14/02/78 | 111 | 8.2 | 891.3 |
| 10/01/78 | 76 | 8.4 | 616.1 | 15/02/78 | 112 | 8.3 | 899.6 |
| 11/01/78 | 77 | 8.4 | 624.5 | 16/02/78 | 113 | 8.4 | 908.0 |
| 12/01/78 | 78 | 8.5 | 633.0 | 17/02/78 | 114 | 8.2 | 916.2 |
| 13/01/78 | 79 | 8.5 | 641.5 | 18/02/78 | 115 | 8.0 | 924.2 |
| 14/01/78 | 80 | 8.2 | 649.7 | 19/02/78 | 116 | 7.8 | 932.0 |
| 15/01/78 | 81 | 8.1 | 657.8 | 20/02/78 | 117 | 8.2 | 940.2 |
| 16/01/78 | 82 | 8.1 | 665.9 | 21/02/78 | 118 | 8.3 | 948.5 |
| 17/01/78 | 83 | 8.1 | 674.0 | 22/02/78 | 119 | 8.6 | 957.1 |
| 18/01/78 | 84 | 8.1 | 682.1 | 23/02/78 | 120 | 8.4 | 965.5 |
| 19/01/78 | 85 | 8.2 | 690.3 | 24/02/78 | 121 | 8.2 | 973.7 |
| 20/01/78 | 86 | 8.1 | 698.4 | 25/02/78 | 122 | 8.3 | 982.0 |
| 21/01/78 | 87 | 7.4 | 705.8 | 26/02/78 | 123 | 8.3 | 990.3 |
| 22/01/78 | 88 | 7.2 | 713.0 | 27/02/78 | 124 | 8.4 | 998.7 |
| 23/01/78 | 89 | 7.5 | 720.5 | 28/02/78 | 125 | 8.6 | 1007.3 |
| 24/01/78 | 90 | 7.6 | 728.1 | | | | |
| 25/01/78 | 91 | 7.4 | 735.5 | | | | |
| 26/01/78 | 92 | 8.0 | 743.5 | | | | |
| 27/01/78 | 93 | 7.8 | 751.3 | | | | |
| 28/01/78 | 94 | 7.9 | 759.2 | | | | |
| 29/01/78 | 95 | 8.1 | 767.3 | | | | |
| 30/01/78 | 96 | 8.2 | 775.5 | | | | |
| 31/01/78 | 97 | 8.1 | 783.6 | | | | |
| 01/02/78 | 98 | 7.9 | 791.5 | | | | |
| 02/02/78 | 99 | 7.9 | 799.4 | | | | |
| 03/02/78 | 100 | 8.1 | 807.5 | | | | |
| 04/02/78 | 101 | 8.2 | 815.7 | | | | |
| 05/02/78 | 102 | 8.2 | 823.9 | | | | |
| 06/02/78 | 103 | 7.8 | 831.7 | | | | |
| 07/02/78 | 104 | 6.8 | 838.5 | | | | |
| 08/02/78 | 105 | 6.7 | 845.2 | | | | |
| 09/02/78 | 106 | 7.3 | 852.5 | | | | |
| 10/02/78 | 107 | 7.4 | 859.9 | | | | |

Appendix III: Mean lengths and weights and their standard deviations (SD) for samples of alevins (N) from Year I experiments.

Tray A3 3005 eggs/tray Flow 12 1/min

| Date | Day From Fertiliz. | N | Length (cm) | SD | Weight (g) | SD | TU °C day |
|---|---|---|---|---|---|---|---|
| 23/12/76 | 55 | | | | | | 520.9 |
| 29/12/76 | 61 | 20 | 2.8 | 0.07 | 0.399 | 0.038 | 573.6 |
| 10/01/77 | 73 | 21 | 3.2 | 0.07 | 0.453 | 0.039 | 677.6 |
| 17/01/77 | 80 | 20 | 3.5 | 0.09 | 0.489 | 0.059 | 738.4 |
| 24/01/77 | 87 | 23 | 3.7 | 0.08 | 0.528 | 0.030 | 800.5 |
| 31/01/77 | 94 | 26 | 3.8 | 0.08 | 0.561 | 0.044 | 861.2 |
| 07/02/77 | 101 | 20 | 4.0 | 0.08 | 0.582 | 0.036 | 926.8 |
| 10/02/77 | 104 | 22 | 4.0 | 0.09 | 0.583 | 0.029 | 955.9 |
| 21/02/77 | 115 | 20 | 4.1 | 0.11 | 0.585 | 0.073 | 1058.5 |
| 28/02/77 | 122 | 20 | 4.2 | 0.11 | 0.662 | 0.060 | 1119.7 |
| 07/03/77 | 129 | 20 | 4.4 | 0.20 | 0.785 | 0.076 | 1180.3 |
| 14/03/77 | 136 | 20 | 4.5 | 0.24 | 0.779 | 0.191 | 1238.4 |
| 22/03/77 | 144 | 20 | 4.8 | 0.41 | 1.057 | 0.340 | 1311.8 |
| 28/03/77 | 150 | 20 | 4.9 | 0.38 | 1.173 | 0.332 | 1367.8 |

Tray A10 3005 eggs/tray Flow 12 1/min

| Date | Day From Fertiliz. | N | Length (cm) | SD | Weight (g) | SD | TU °C day |
|---|---|---|---|---|---|---|---|
| 23/12/76 | 55 | | | | | | 520.9 |
| 29/12/76 | 61 | 20 | 2.8 | 0.06 | 0.411 | 0.40 | 573.6 |
| 10/01/77 | 73 | 21 | 3.2 | 0.08 | 0.437 | 0.053 | 677.6 |
| 17/01/77 | 80 | 23 | 3.4 | 0.14 | 0.446 | 0.062 | 738.4 |
| 24/01/77 | 87 | 22 | 3.6 | 0.11 | 0.513 | 0.047 | 800.5 |
| 31/01/77 | 94 | 25 | 3.7 | 0.13 | 0.540 | 0.050 | 861.2 |
| 07/02/77 | 101 | 21 | 3.9 | 0.19 | 0.564 | 0.059 | 926.8 |
| 10/02/77 | 104 | 21 | 3.9 | 0.14 | 0.530 | 0.064 | 955.9 |
| 21/02/77 | 115 | 20 | 4.1 | 0.11 | 0.570 | 0.054 | 1058.5 |
| 28/02/77 | 122 | 20 | 4.2 | 0.20 | 0.660 | 0.144 | 1119.7 |
| 07/03/77 | 129 | 20 | 4.3 | 0.22 | 0.701 | 0.154 | 1180.3 |
| 14/03/77 | 136 | 20 | 4.4 | 0.26 | 0.732 | 0.176 | 1238.4 |
| 22/03/77 | 144 | 20 | 4.8 | 0.31 | 1.046 | 0.237 | 1311.8 |
| 28/03/77 | 150 | 20 | 4.9 | 0.44 | 1.213 | 0.436 | 1367.8 |

Appendix III cont'd

Tray B3 4252 eggs/tray Flow 12 1/min

| Date | Day From Fertiliz. | N | Length (cm) | SD | Weight (g) | SD | TU °C day |
|---|---|---|---|---|---|---|---|
| 23/12/76 | 55 | | | | | | 520.9 |
| 30/12/76 | 62 | 20 | 2.8 | 0.07 | 0.408 | 0.025 | 582.4 |
| 10/01/77 | 73 | 22 | 3.2 | 0.09 | 0.443 | 0.039 | 677.6 |
| 17/01/77 | 80 | 20 | 3.5 | 0.08 | 0.509 | 0.046 | 738.4 |
| 24/01/77 | 87 | 22 | 3.6 | 0.08 | 0.512 | 0.043 | 800.5 |
| 31/01/77 | 94 | 23 | 3.8 | 0.11 | 0.568 | 0.052 | 861.2 |
| 07/02/77 | 101 | 28 | 3.9 | 0.12 | 0.581 | 0.052 | 926.8 |
| 10/02/77 | 104 | 21 | 3.9 | 0.16 | 0.550 | 0.056 | 955.9 |
| 21/02/77 | 115 | 20 | 4.2 | 0.09 | 0.607 | 0.064 | 1058.5 |
| 28/02/77 | 122 | 20 | 4.2 | 0.19 | 0.619 | 0.126 | 1119.7 |
| 07/03/77 | 129 | 20 | 4.5 | 0.14 | 0.829 | 0.097 | 1180.3 |
| 14/03/77 | 136 | 20 | 4.6 | 0.26 | 0.886 | 0.169 | 1238.4 |
| 22/03/77 | 144 | 20 | 4.8 | 0.41 | 1.057 | 0.340 | 1311.8 |
| 28/03/77 | 150 | 20 | 4.9 | 0.36 | 1.155 | 0.273 | 1367.8 |

Tray B7 4252 eggs/tray Flow 12 L/min

| Date | Day From Fertiliz. | N | Length (cm) | SD | Weight (g) | SD | TU °C day |
|---|---|---|---|---|---|---|---|
| 23/12/76 | 55 | | | | | | 520.9 |
| 30/12/76 | 62 | 20 | 2.8 | 0.11 | 0.376 | 0.046 | 582.4 |
| 10/01/77 | 73 | 22 | 3.2 | 0.07 | 0.447 | 0.042 | 677.6 |
| 17/01/77 | 80 | 23 | 3.4 | 0.13 | 0.461 | 0.062 | 738.4 |
| 24/01/77 | 87 | 23 | 3.6 | 0.13 | 0.526 | 0.042 | 800.5 |
| 31/01/77 | 94 | 20 | 3.8 | 0.15 | 0.554 | 0.055 | 861.2 |
| 07/02/77 | 101 | 25 | 3.9 | 0.12 | 0.573 | 0.057 | 926.8 |
| 10/02/77 | 104 | 20 | 4.0 | 0.14 | 0.571 | 0.069 | 955.9 |
| 21/02/77 | 115 | 20 | 4.2 | 0.13 | 0.618 | 0.068 | 1058.5 |
| 28/02/77 | 122 | 20 | 4.2 | 0.13 | 0.646 | 0.118 | 1119.7 |
| 07/03/77 | 129 | 20 | 4.4 | 0.18 | 0.750 | 0.126 | 1180.3 |
| 14/03/77 | 136 | 20 | 4.6 | 0.19 | 0.874 | 0.111 | 1238.4 |
| 22/03/77 | 144 | 20 | 4.7 | 0.20 | 0.964 | 0.167 | 1311.8 |
| 28/03/77 | 150 | 20 | 4.9 | 0.46 | 1.167 | 0.345 | 1367.8 |

Appendix III cont'd

Tray C3 5499 eggs/tray Flow 12 l/min

| Date | Day From Fertiliz. | N | Length (cm) | SD | Weight (g) | SD | TU °C day |
|---|---|---|---|---|---|---|---|
| 23/12/76 | 55 | | | | | | 520.9 |
| 30/12/76 | 62 | 21 | 2.8 | 0.05 | 0.404 | 0.033 | 582.4 |
| 10/01/77 | 73 | 23 | 3.2 | 0.08 | 0.460 | 0.034 | 677.6 |
| 17/01/77 | 80 | 22 | 3.4 | 0.11 | 0.499 | 0.032 | 738.4 |
| 24/01/77 | 87 | 24 | 3.7 | 0.10 | 0.531 | 0.037 | 800.5 |
| 31/01/77 | 94 | 21 | 3.9 | 0.10 | 0.575 | 0.048 | 861.2 |
| 07/02/77 | 101 | 24 | 3.9 | 0.11 | 0.578 | 0.043 | 926.8 |
| 10/02/77 | 104 | 20 | 4.0 | 0.08 | 0.582 | 0.053 | 955.9 |
| 21/02/77 | 115 | 20 | 4.1 | 0.07 | 0.606 | 0.049 | 1058.5 |
| 28/02/77 | 122 | 20 | 4.2 | 0.13 | 0.060 | 0.078 | 1119.7 |
| 07/03/77 | 129 | 20 | 4.5 | 0.22 | 0.859 | 0.144 | 1180.3 |
| 14/03/77 | 136 | 20 | 4.7 | 0.23 | 0.974 | 0.159 | 1238.4 |
| 22/03/77 | 144 | 20 | 4.7 | 0.23 | 0.991 | 0.157 | 1311.8 |
| 28/03/77 | 150 | 20 | 5.0 | 0.36 | 1.135 | 0.294 | 1367.8 |

Tray C6 5499 eggs/tray Flow 12 l/min

| Date | Day From Fertiliz. | N | Length (cm) | SD | Weight (g) | SD | TU °C day |
|---|---|---|---|---|---|---|---|
| 23/12/76 | 55 | | | | | | 520.9 |
| 30/12/76 | 62 | 20 | 2.8 | 0.07 | 0.397 | 0.044 | 582.4 |
| 10/01/77 | 73 | 20 | 3.2 | 0.09 | 0.455 | 0.039 | 677.6 |
| 17/01/77 | 80 | 22 | 3.5 | 0.07 | 0.497 | 0.028 | 738.4 |
| 24/01/77 | 87 | 22 | 3.7 | 0.11 | 0.529 | 0.037 | 800.5 |
| 31/01/77 | 94 | 20 | 3.8 | 0.15 | 0.551 | 0.054 | 861.2 |
| 07/02/77 | 101 | 23 | 3.9 | 0.14 | 0.583 | 0.056 | 926.8 |
| 10/02/77 | 104 | 19 | 4.0 | 0.09 | 0.588 | 0.043 | 955.9 |
| 21/02/77 | 115 | 20 | 4.1 | 0.10 | 0.552 | 0.066 | 1058.5 |
| 28/02/77 | 122 | 20 | 4.2 | 0.14 | 0.660 | 0.105 | 1119.7 |
| 07/03/77 | 129 | 20 | 4.4 | 0.19 | 0.745 | 0.144 | 1180.3 |
| 14/03/77 | 136 | 20 | 4.5 | 0.27 | 0.802 | 0.211 | 1238.4 |
| 22/03/77 | 144 | 20 | 4.6 | 0.32 | 0.896 | 0.255 | 1311.8 |
| 28/03/77 | 150 | 20 | 4.6 | 0.36 | 0.896 | 0.300 | 1367.8 |

Appendix III cont'd

Tray D3 6745 eggs/tray Flow 12 l/min

| Date | Day From Fertiliz. | N | Length (cm) | SD | Weight (g) | SD | TU °C day |
|---|---|---|---|---|---|---|---|
| 23/12/76 | 55 | | | | | | 520.9 |
| 30/12/76 | 62 | 20 | 2.8 | 0.07 | 0.410 | 0.033 | 582.4 |
| 10/01/77 | 73 | 22 | 3.2 | 0.08 | 0.468 | 0.023 | 677.6 |
| 17/01/77 | 80 | 22 | 3.5 | 0.06 | 0.491 | 0.041 | 738.4 |
| 24/01/77 | 87 | 20 | 3.7 | 0.10 | 0.538 | 0.041 | 800.5 |
| 31/01/77 | 94 | 20 | 3.8 | 0.09 | 0.556 | 0.045 | 861.2 |
| 07/02/77 | 101 | 25 | 3.9 | 0.09 | 0.577 | 0.050 | 926.8 |
| 10/02/77 | 104 | 20 | 4.0 | 0.08 | 0.571 | 0.035 | 955.9 |
| 21/02/77 | 115 | 20 | 4.1 | 0.08 | 0.579 | 0.067 | 1058.5 |
| 28/02/77 | 122 | 20 | 4.2 | 0.13 | 0.652 | 0.101 | 1119.7 |
| 07/03/77 | 129 | 20 | 4.4 | 0.25 | 0.766 | 0.187 | 1180.3 |
| 14/03/77 | 136 | 20 | 4.5 | 0.25 | 0.785 | 0.166 | 1238.4 |
| 22/03/77 | 144 | 20 | 4.5 | 0.27 | 0.848 | 0.193 | 1311.8 |
| 28/03/77 | 150 | 20 | 4.8 | 0.46 | 1.068 | 0.326 | 1367.8 |

Tray D5 6745 eggs/tray Flow 12 l/min

| Date | Day From Fertiliz. | N | Length (cm) | SD | Weight (g) | SD | TU °C day |
|---|---|---|---|---|---|---|---|
| 23/12/76 | 55 | | | | | | 520.9 |
| 30/12/76 | 62 | 20 | 2.8 | 0.08 | 0.392 | 0.045 | 582.4 |
| 10/01/77 | 73 | 21 | 3.2 | 0.09 | 0.462 | 0.041 | 677.6 |
| 17/01/77 | 80 | 23 | 3.4 | 0.08 | 0.482 | 0.035 | 738.4 |
| 24/01/77 | 87 | 21 | 3.6 | 0.14 | 0.503 | 0.058 | 800.5 |
| 31/01/77 | 94 | 21 | 3.8 | 0.07 | 0.553 | 0.036 | 861.2 |
| 07/02/77 | 101 | 25 | 3.9 | 0.12 | 0.572 | 0.052 | 926.8 |
| 10/02/77 | 104 | 21 | 4.0 | 0.12 | 0.580 | 0.053 | 955.9 |
| 21/02/77 | 115 | 20 | 4.1 | 0.09 | 0.593 | 0.057 | 1058.5 |
| 28/02/77 | 122 | 20 | 4.2 | 0.14 | 0.659 | 0.100 | 1119.7 |
| 07/03/77 | 129 | 20 | 4.3 | 0.22 | 0.657 | 0.143 | 1180.3 |
| 14/03/77 | 136 | 20 | 4.5 | 0.24 | 0.781 | 0.156 | 1238.4 |
| 22/03/77 | 144 | 20 | 4.6 | 0.29 | 0.834 | 0.218 | 1311.8 |
| 28/03/77 | 150 | 20 | 4.9 | 0.28 | 1.085 | 0.218 | 1367.8 |

Appendix III cont'd

Tray E3 7992 eggs/tray Flow 12 1/min

| Date | Day From Fertiliz. | N | Length (cm) | SD | Weight (g) | SD | TU °C day |
|---|---|---|---|---|---|---|---|
| 23/12/76 | 55 | | | | | | 520.9 |
| 30/12/76 | 62 | 21 | 2.8 | 0.07 | 0.414 | 0.031 | 582.4 |
| 10/01/77 | 73 | 28 | 3.2 | 0.06 | 0.458 | 0.035 | 677.6 |
| 17/01/77 | 80 | 23 | 3.4 | 0.07 | 0.499 | 0.040 | 738.4 |
| 24/01/77 | 87 | 23 | 3.7 | 0.07 | 0.537 | 0.041 | 800.5 |
| 31/01/77 | 94 | 24 | 3.8 | 0.08 | 0.555 | 0.038 | 861.2 |
| 07/02/77 | 101 | 27 | 4.0 | 0.08 | 0.587 | 0.039 | 926.8 |
| 10/02/77 | 104 | 21 | 4.0 | 0.11 | 0.574 | 0.046 | 955.9 |
| 21/02/77 | 115 | 20 | 4.1 | 0.09 | 0.592 | 0.048 | 1058.5 |
| 28/02/77 | 122 | 20 | 4.2 | 0.15 | 0.670 | 0.097 | 1119.7 |
| 07/03/77 | 129 | 20 | 4.4 | 0.22 | 0.791 | 0.153 | 1180.3 |
| 14/03/77 | 136 | 20 | 4.6 | 0.19 | 0.840 | 0.139 | 1238.4 |
| 22/03/77 | 144 | 20 | 4.8 | 0.23 | 1.013 | 0.160 | 1311.8 |
| 28/03/77 | 150 | 20 | 5.1 | 0.43 | 1.356 | 0.415 | 1367.8 |

Tray E5 7992 eggs/tray Flow 12 1/min

| Date | Day From Fertiliz. | N | Length (cm) | SD | Weight (g) | SD | TU °C day |
|---|---|---|---|---|---|---|---|
| 23/12/76 | 55 | | | | | | 520.9 |
| 30/12/76 | 62 | 21 | 2.8 | 0.07 | 0.394 | 0.042 | 582.4 |
| 10/01/77 | 73 | 22 | 3.2 | 0.07 | 0.462 | 0.038 | 677.6 |
| 17/01/77 | 80 | 23 | 3.4 | 0.08 | 0.494 | 0.038 | 738.4 |
| 24/01/77 | 87 | 22 | 3.7 | 0.12 | 0.526 | 0.051 | 800.5 |
| 31/01/77 | 94 | 22 | 3.8 | 0.09 | 0.553 | 0.051 | 861.2 |
| 07/02/77 | 101 | 25 | 3.9 | 0.10 | 0.574 | 0.044 | 926.8 |
| 10/02/77 | 104 | 21 | 4.0 | 0.07 | 0.568 | 0.036 | 955.9 |
| 21/02/77 | 115 | 20 | 4.1 | 0.09 | 0.600 | 0.050 | 1058.5 |
| 28/02/77 | 122 | 20 | 4.2 | 0.13 | 0.585 | 0.053 | 1119.7 |
| 07/03/77 | 129 | 20 | 4.4 | 0.12 | 0.744 | 0.118 | 1180.3 |
| 14/03/77 | 136 | 20 | 4.5 | 0.20 | 0.761 | 0.154 | 1238.4 |
| 22/03/77 | 144 | 20 | 4.6 | 0.31 | 0.915 | 0.242 | 1311.8 |
| 28/03/77 | 150 | 20 | 4.9 | 0.32 | 1.122 | 0.280 | 1367.8 |

Appendix IV: Mean lengths and weights and their standard deviations (SD) for samples of alevins (N) from Year II experiments.

## Group A

Tray C-3 5500 eggs/tray Flow 12 l/min

| Date | Day From Fertiliz. | N | Length (cm) | SD | Weight (g) | SD | TU °C day |
|---|---|---|---|---|---|---|---|
| 03/01/78 | 69 | 20 | 2.70 | 0.110 | 0.437 | 0.045 | 560.8 |
| 30/01/78 | 96 | 20 | 3.60 | 0.069 | 0.541 | 0.052 | 775.5 |
| 08/02/78 | 105 | 19 | 3.88 | 0.093 | 0.578 | 0.040 | 845.2 |
| 15/02/78 | 112 | 20 | 3.99 | 0.091 | 0.598 | 0.048 | 899.6 |
| 20/02/78 | 117 | 20 | 4.10 | 0.119 | 0.665 | 0.054 | 940.2 |

Tray C-10 5500 eggs/tray Flow 12 l/min

| Date | Day From Fertiliz. | N | Length (cm) | SD | Weight (g) | SD | TU °C day |
|---|---|---|---|---|---|---|---|
| 03/01/78 | 69 | 20 | 2.72 | 0.085 | 0.462 | 0.034 | 560.8 |
| 30/01/78 | 96 | 20 | 3.73 | 0.125 | 0.555 | 0.042 | 775.5 |
| 08/02/78 | 105 | 19 | 3.88 | 0.079 | 0.600 | 0.053 | 845.2 |
| 15/02/78 | 112 | 22 | 3.99 | 0.115 | 0.625 | 0.050 | 899.6 |
| 20/02/78 | 117 | 25 | 4.08 | 0.100 | 0.636 | 0.046 | 940.2 |

Tray D-3 5500 eggs/tray Flow 12 l/min

| Date | Day From Fertiliz. | N | Length (cm) | SD | Weight (g) | SD | TU °C day |
|---|---|---|---|---|---|---|---|
| 03/01/78 | 69 | 20 | 2.71 | 0.102 | 0.417 | 0.041 | 560.8 |
| 30/01/78 | 96 | 19 | 3.65 | 0.096 | 0.536 | 0.045 | 775.5 |
| 08/02/78 | 105 | 20 | 3.84 | 0.083 | 0.590 | 0.055 | 845.2 |
| 15/02/78 | 112 | 20 | 3.99 | 0.083 | 0.622 | 0.050 | 899.6 |
| 20/02/78 | 117 | 20 | 4.05 | 0.084 | 0.636 | 0.058 | 940.2 |

Appendix IV cont'd

Tray D-10 5500 eggs/tray Flow 12 l/min

| Date | Day From Fertiliz. | N | Length (cm) | SD | Weight (g) | SD | TU °C day |
|---|---|---|---|---|---|---|---|
| 03/01/78 | 69 | 23 | 2.73 | 0.107 | 0.423 | 0.036 | 560.8 |
| 30/01/78 | 96 | 20 | 3.66 | 0.099 | 0.548 | 0.045 | 775.5 |
| 08/02/78 | 105 | 21 | 3.84 | 0.059 | 0.577 | 0.054 | 845.2 |
| 15/02/78 | 112 | 25 | 3.98 | 0.084 | 0.634 | 0.049 | 899.6 |
| 20/02/78 | 117 | 20 | 4.13 | 0.104 | 0.639 | 0.063 | 940.2 |

Tray E-9 4000 eggs/tray Flow 8 l/min

| Date | Day From Fertiliz. | N | Length (cm) | SD | Weight (g) | SD | TU °C day |
|---|---|---|---|---|---|---|---|
| 03/01/78 | 69 | 19 | 2.69 | 0.074 | 0.427 | 0.040 | 560.8 |
| 30/01/78 | 96 | 20 | 3.70 | 0.076 | 0.556 | 0.043 | 775.5 |
| 08/02/78 | 105 | 19 | 3.87 | 0.075 | 0.555 | 0.053 | 845.2 |
| 15/02/78 | 112 | 20 | 4.00 | 0.076 | 0.614 | 0.054 | 899.6 |
| 20/02/78 | 117 | 20 | 4.07 | 0.114 | 0.615 | 0.058 | 940.2 |

Tray F-9 8000 eggs/tray Flow 8 l/min

| Date | Day From Fertiliz. | N | Length (cm) | SD | Weight (g) | SD | TU °C day |
|---|---|---|---|---|---|---|---|
| 03/01/78 | 69 | 20 | 2.75 | 0.051 | 0.411 | 0.050 | 560.8 |
| 30/01/78 | 96 | 20 | 3.68 | 0.081 | 0.539 | 0.052 | 775.5 |
| 08/02/78 | 105 | 20 | 3.85 | 0.076 | 0.575 | 0.053 | 845.2 |
| 15/02/78 | 112 | 21 | 3.93 | 0.102 | 0.566 | 0.069 | 899.6 |
| 20/02/78 | 117 | 20 | 4.02 | 0.121 | 0.590 | 0.068 | 940.2 |

Tray G-9 6000 eggs/tray Flow 12 l/min

| Date | Day From Fertiliz. | N | Length (cm) | SD | Weight (g) | SD | TU °C day |
|---|---|---|---|---|---|---|---|
| 04/01/78 | 70 | 20 | 2.76 | 0.050 | 0.436 | 0.042 | 568.0 |
| 30/01/78 | 96 | 20 | 3.68 | 0.081 | 0.551 | 0.051 | 775.5 |
| 08/02/78 | 105 | 21 | 3.85 | 0.081 | 0.539 | 0.050 | 845.2 |
| 15/02/78 | 112 | 20 | 3.96 | 0.104 | 0.585 | 0.058 | 899.6 |
| 20/02/78 | 117 | 21 | 4.02 | 0.129 | 0.558 | 0.064 | 940.2 |

Appendix IV cont'd

Tray H-9 4000 eggs/tray Flow 16 l/min

| Date | Day From Fertiliz. | N | Length (cm) | SD | Weight (g) | SD | TU °C day |
|---|---|---|---|---|---|---|---|
| 04/01/78 | 70 | 27 | 2.74 | 0.079 | 0.431 | 0.049 | 568.0 |
| 31/01/78 | 97 | 20 | 3.70 | 0.086 | 0.554 | 0.047 | 783.6 |
| 08/02/78 | 105 | 20 | 3.79 | 0.069 | 0.568 | 0.066 | 845.2 |
| 15/02/78 | 112 | 20 | 3.94 | 0.089 | 0.592 | 0.059 | 899.6 |
| 20/02/78 | 117 | 20 | 4.00 | 0.051 | 0.580 | 0.042 | 940.2 |

Tray I-9 8000 eggs/tray Flow 16 l/min

| Date | Day From Fertiliz. | N | Length (cm) | SD | Weight (g) | SD | TU °C day |
|---|---|---|---|---|---|---|---|
| 04/01/78 | 70 | 20 | 2.71 | 0.064 | 0.422 | 0.045 | 568.0 |
| 31/01/78 | 97 | 20 | 3.68 | 0.081 | 0.538 | 0.049 | 783.6 |
| 09/02/78 | 106 | 22 | 3.86 | 0.080 | 0.580 | 0.055 | 852.5 |
| 15/02/78 | 112 | 20 | 3.99 | 0.094 | 0.590 | 0.059 | 899.6 |
| 20/02/78 | 117 | 22 | 4.06 | 0.095 | 0.591 | 0.064 | 940.2 |

Group B

Tray E-13 6000 eggs/tray Flow 4 l/min

| Date | Day From Fertiliz. | N | Length (cm) | SD | Weight (g) | SD | TU °C day |
|---|---|---|---|---|---|---|---|
| 04/01/78 | 70 | 20 | 2.68 | 0.101 | 0.423 | 0.042 | 568.0 |
| 30/01/78 | 96 | 20 | 3.65 | 0.100 | 0.527 | 0.059 | 775.5 |
| 08/02/78 | 105 | 20 | 3.79 | 0.110 | 0.552 | 0.058 | 845.2 |
| 15/02/78 | 112 | 20 | 3.96 | 0.136 | 0.602 | 0.602 | 899.6 |
| 20/02/78 | 117 | 20 | 3.99 | 0.136 | 0.587 | 0.078 | 940.2 |

Appendix IV cont´d

Tray F-13 6000 eggs/tray Flow 4 l/min

| Date | Day From Fertiliz. | N | Length (cm) | SD | Weight (g) | SD | TU °C day |
|---|---|---|---|---|---|---|---|
| 04/01/78 | 70 | 20 | 2.71 | 0.097 | 0.424 | 0.060 | 568.0 |
| 30/01/78 | 96 | 20 | 3.68 | 0.088 | 0.545 | 0.055 | 775.5 |
| 08/02/78 | 105 | 20 | 3.86 | 0.115 | 0.586 | 0.063 | 845.2 |
| 15/02/78 | 112 | 21 | 3.95 | 0.117 | 0.608 | 0.046 | 899.6 |
| 20/02/78 | 117 | 20 | 4.06 | 0.128 | 0.603 | 0.065 | 940.2 |

Tray G-13 4000 eggs/tray Flow 8 l/min

| Date | Day From Fertiliz. | N | Length (cm) | SD | Weight (g) | SD | TU °C day |
|---|---|---|---|---|---|---|---|
| 04/01/78 | 70 | 20 | 2.74 | 0.099 | 0.428 | 0.074 | 568.0 |
| 30/01/78 | 96 | 21 | 3.67 | 0.127 | 0.551 | 0.062 | 775.5 |
| 08/02/78 | 105 | 19 | 3.84 | 0.106 | 0.620 | 0.065 | 845.2 |
| 15/02/78 | 112 | 21 | 3.97 | 0.114 | 0.635 | 0.050 | 899.6 |
| 20/02/78 | 117 | 21 | 4.02 | 0.175 | 0.591 | 0.104 | 940.2 |

Tray H-13 8000 eggs/tray Flow 8 l/min

| Date | Day From Fertiliz. | N | Length (cm) | SD | Weight (g) | SD | TU °C day |
|---|---|---|---|---|---|---|---|
| 04/01/78 | 70 | 20 | 2.75 | 0.083 | 0.458 | 0.041 | 568.0 |
| 31/01/78 | 9? | 20 | 3.65 | 0.094 | 0.556 | 0.042 | 783.6 |
| 08/02/78 | 105 | 21 | 3.85 | 0.087 | 0.593 | 0.055 | 845.2 |
| 15/02/78 | 112 | 20 | 3.94 | 0.122 | 0.594 | 0.081 | 899.6 |
| 20/02/78 | 117 | 21 | 4.05 | 0.129 | 0.608 | 0.084 | 940.2 |

Tray I-13 6000 eggs/tray Flow 12 l/min

| Date | Day From Fertiliz. | N | Length (cm) | SD | Weight (g) | SD | TU °C day |
|---|---|---|---|---|---|---|---|
| 04/01/78 | 70 | 21 | 2.68 | 0.089 | 0.408 | 0.077 | 568.0 |
| 31/01/78 | 97 | 20 | 3.68 | 0.095 | 0.563 | 0.063 | 783.6 |
| 09/02/78 | 106 | 21 | 3.85 | 0.087 | 0.597 | 0.067 | 852.5 |
| 15/02/78 | 112 | 20 | 3.93 | 0.159 | 0.596 | 0.108 | 899.6 |
| 20/02/78 | 117 | 20 | 4.10 | 0.130 | 0.623 | 0.061 | 940.2 |

Appendix IV cont´d

Tray J-13 4000 eggs/tray Flow 16 l/min

| Date | Day From Fertiliz. | N | Length (cm) | SD | Weight (g) | SD | TU °C day |
|---|---|---|---|---|---|---|---|
| 04/01/78 | 70 | 21 | 2.714 | 0.085 | 0.447 | 0.069 | 568.0 |
| 31/01/78 | 97 | 20 | 3.710 | 0.887 | 0.572 | 0.035 | 783.6 |
| 09/02/78 | 106 | 20 | 3.890 | 0.117 | 0.601 | 0.076 | 852.5 |
| 15/02/78 | 112 | 20 | 3.960 | 0.088 | 0.611 | 0.060 | 899.6 |
| 20/02/78 | 117 | 20 | 3.960 | 0.135 | 0.574 | 0.103 | 940.2 |

Tray K-13 8000 eggs/tray Flow 16 l/min

| Date | Day From Fertiliz. | N | Length (cm) | SD | Weight (g) | SD | TU °C day |
|---|---|---|---|---|---|---|---|
| 04/01/78 | 70 | 24 | 2.73 | 0.055 | 0.435 | 0.054 | 568.0 |
| 31/01/78 | 97 | 23 | 3.67 | 0.096 | 0.558 | 0.042 | 783.6 |
| 09/02/78 | 106 | 21 | 3.87 | 0.057 | 0.611 | 0.041 | 852.5 |
| 15/02/78 | 112 | 20 | 3.97 | 0.129 | 0.613 | 0.093 | 899.6 |
| 20/02/78 | 117 | 22 | 3.98 | 0.131 | 0.578 | 0.086 | 940.2 |

Appendix V: Water quality data generated during the study is summarized in the following tables. Results for stacks A, B, C, D, and E are shown for Year I. Year II shows data averaged over two 7-tray stacks loaded at 5500 eggs per tray.

Year I, Stack A: 3005 eggs/tray, 8 trays per stack

| Sample Date | Dec 17/76 | Dec 22 | Dec 31 | Jan 7/77 | Jan 11 | Jan 18 | Jan 25 | Feb 1 | Feb 8 |
|---|---|---|---|---|---|---|---|---|---|
| Days From Fertiliz. | 49 | 54 | 63 | 70 | 74 | 81 | 88 | 95 | 102 |
| TU °C Days | 466 | 512 | 591 | 652 | 686 | 747 | 809 | 870 | 937 |
| Temp. °C | 9.8 | 9.5 | 8.5 | 8.7 | 8.9 | 9.2 | 8.3 | 9.2 | 9.7 |
| Flow (l/min) | 12.0 | 11.5 | 11.7 | 12.0 | 12.0 | 11.8 | 11.4 | 11.9 | 11.4 |
| Diss. Oxygen (mg/l) | | | | | | | | | |
| IN | 11.15 | 11.25 | 11.70 | 11.65 | 11.40 | 11.77 | 11.80 | 11.32 | 10.69 |
| OUT | 10.86 | 11.18 | 10.31 | 10.07 | 9.48 | 9.97 | 9.10 | 8.34 | 7.52 |
| Rate (mg/1000/hr) | 12.9 | 4.5 | 50.5 | 58.9 | 74.5 | 63.0 | 96.3 | 114.5 | 123.1 |
| Ammonia-N (ug/l) | | | | | | | | | |
| IN | 2 | 5 | <2 | <2 | 3 | 3 | <2 | 3 | <2 |
| OUT | 15 | 19 | 54 | 60 | 69 | 102 | 85 | 104 | 120 |
| Rate (mg/1000/hr) | 0.39 | 0.40 | 1.60 | 1.82 | 2.01 | 2.97 | 2.47 | 3.08 | 3.57 |
| pH | | | | | | | | | |
| IN | 7.66 | 7.58 | 7.71 | 7.77 | 7.74 | 7.73 | 7.73 | 7.77 | 7.82 |
| OUT | 7.63 | 7.60 | 7.51 | 7.46 | 7.41 | 7.33 | 7.40 | 7.26 | 7.28 |

Appendix V cont'd...

Year I, Stack B: 4252 eggs/tray, 5 trays per stack

| Sample Date | Dec 17/76 | Dec 22 | Dec 31 | Jan 7/77 | Jan 11 | Jan 18 | Jan 25 | Feb 1 | Feb 8 |
|---|---|---|---|---|---|---|---|---|---|
| Days From Fertiliz. | 49 | 54 | 63 | 70 | 74 | 81 | 88 | 95 | 102 |
| TU °C Days | 466 | 512 | 591 | 652 | 686 | 747 | 809 | 870 | 937 |
| Temp. °C | 9.8 | 9.5 | 8.5 | 8.7 | 8.9 | 9.2 | 8.3 | 9.2 | 9.7 |
| Flow (l/min) | 12.4 | 12.2 | 12.2 | 12.3 | 12.2 | 12.0 | 12.2 | 12.4 | 12.2 |
| Diss. Oxygen (mg/l) | | | | | | | | | |
| IN | 11.15 | 11.25 | 11.70 | 11.65 | 11.40 | 11.77 | 11.80 | 11.32 | 10.69 |
| OUT | 10.83 | 10.91 | 10.56 | 10.07 | 9.18 | 10.02 | 9.50 | 8.98 | 7.22 |
| Rate (mg/1000/hr) | 14.4 | 15.0 | 45.3 | 63.4 | 90.5 | 66.9 | 92.0 | 97.8 | 147.1 |
| Ammonia-N (ug/l) | | | | | | | | | |
| IN | 2 | 5 | -- | <2 | 3 | 3 | <2 | 3 | <2 |
| OUT | 13 | 17 | 45 | 52 | 67 | 77 | 66 | 83 | 118 |
| Rate (mg/1000/hr) | 0.39 | 0.42 | 1.57 | 1.83 | 2.24 | 2.56 | 2.33 | 2.88 | 4.19 |
| pH | | | | | | | | | |
| IN | 7.66 | 7.58 | 7.71 | 7.77 | 7.74 | 7.73 | 7.73 | 7.77 | 7.82 |
| OUT | 7.63 | 7.61 | 7.53 | 7.51 | 7.39 | 7.29 | 7.42 | 7.33 | 7.22 |

Appendix V cont'd...

Year I, Stack C: 5499 eggs/tray, 4 trays per stack

| Sample Date | Dec 17/76 | Dec 22 | Dec 31 | Jan 7/77 | Jan 11 | Jan 18 | Jan 25 | Feb 1 | Feb 8 |
|---|---|---|---|---|---|---|---|---|---|
| Days From Fertiliz. | 49 | 54 | 63 | 70 | 74 | 81 | 88 | 95 | 102 |
| TU °C Days | 466 | 512 | 591 | 652 | 686 | 747 | 809 | 870 | 937 |
| Temp. °C | 9.8 | 9.5 | 8.5 | 8.7 | 8.9 | 9.0 | 8.3 | 9.2 | 9.7 |
| Flow (l/min) | 12.2 | 11.9 | 11.8 | 12.2 | 12.0 | 11.9 | 11.9 | 12.0 | 12.1 |
| Diss. Oxygen (mg/l) | | | | | | | | | |
| IN | 11.15 | 11.25 | 11.70 | 11.65 | 11.40 | 11.77 | 11.80 | 11.32 | 10.69 |
| OUT | 10.66 | 10.78 | 10.76 | 9.82 | 8.78 | 9.99 | 9.20 | 8.91 | 7.25 |
| Rate (mg/1000/hr) | 19.4 | 18.3 | 34.1 | 68.8 | 98.6 | 64.0 | 95.8 | 91.6 | 135 |
| Ammonia-N (ug/l) | | | | | | | | | |
| IN | 2 | 5 | -- | <2 | 3 | 3 | <2 | 3 | <2 |
| OUT | 14 | 18 | 43 | 57 | 66 | 100 | 81 | 90 | 70 |
| Rate (mg/1000/hr) | 0.40 | 0.43 | 1.41 | 1.93 | 2.10 | 3.22 | 2.70 | 2.93 | 2.39 |
| pH | | | | | | | | | |
| IN | 7.66 | 7.58 | 7.71 | 7.77 | 7.74 | 7.73 | 7.73 | 7.77 | 7.82 |
| OUT | 7.62 | 7.61 | 7.54 | 7.45 | 7.37 | 7.20 | 7.35 | 7.32 | 7.23 |

Appendix V cont'd...

Year I, Stack D: 6745 egg/tray, 3 trays per stack

| Sample Date | Dec 17/76 | Dec 22 | Dec 31 | Jan 7/77 | Jan 11 | Jan 18 | Jan 25 | Feb 1 | Feb 8 |
|---|---|---|---|---|---|---|---|---|---|
| Days From Fertiliz. | 49 | 54 | 63 | 70 | 74 | 81 | 88 | 95 | 102 |
| TU °C Days | 466 | 512 | 591 | 652 | 686 | 747 | 809 | 870 | 937 |
| Temp. °C | 9.8 | 9.5 | 8.5 | 8.7 | 8.9 | 9.2 | 8.3 | 9.2 | 9.7 |
| Flow (l/min) | 12.4 | 11.8 | 11.6 | 11.9 | 11.8 | 11.8 | 11.1 | 12.1 | 12.0 |
| Diss. Oxygen (mg/l) | | | | | | | | | |
| IN | 11.15 | 11.25 | 11.70 | 11.65 | 11.40 | 11.77 | 11.80 | 11.32 | 10.69 |
| OUT | 10.83 | 10.83 | 10.68 | 10.22 | 9.18 | 9.80 | 9.60 | 9.52 | 8.54 |
| Rate (mg/1000/hr) | 13.8 | 17.0 | 38.5 | 55.4 | 86.7 | 74.6 | 80.0 | 73.0 | 89.5 |
| Ammonia-N (ug/l) | | | | | | | | | |
| IN | 2 | 5 | -- | <2 | 3 | 3 | <2 | 3 | <2 |
| OUT | 17 | 17 | 43 | 51 | 69 | 90 | 74 | 77 | 76 |
| Rate (mg/1000/hr) | 0.55 | 0.42 | 1.50 | 1.83 | 2.35 | 3.11 | 2.50 | 2.73 | 2.79 |
| pH | | | | | | | | | |
| IN | 7.66 | 7.58 | 7.71 | 7.77 | 7.74 | 7.73 | 7.73 | 7.77 | 7.82 |
| OUT | 7.61 | 7.59 | 7.52 | 7.48 | 7.37 | 7.23 | 7.39 | 7.39 | 7.29 |

Appendix V cont'd...

Year I, Stack E: 7992 eggs/tray, 3 trays per stack

| Sample Date | Dec 17/76 | Dec 22 | Dec 31 | Jan 7/77 | Jan 11 | Jan 18 | Jan 25 | Feb 1 | Feb 8 |
|---|---|---|---|---|---|---|---|---|---|
| Days From Fertiliz. | 49 | 54 | 63 | 70 | 74 | 81 | 88 | 95 | 102 |
| TU °C Days | 466 | 512 | 591 | 652 | 686 | 747 | 809 | 870 | 937 |
| Temp. °C | 9.8 | 9.5 | 8.5 | 8.7 | 8.9 | 9.2 | 8.3 | 9.2 | 9.7 |
| Flow (l/min) | 12.2 | 11.9 | 11.7 | 11.9 | 11.8 | 11.8 | 11.1 | 12.1 | 12.0 |
| Diss. Oxygen (mg/l) | | | | | | | | | |
| IN | 11.15 | 11.25 | 11.70 | 11.65 | 11.40 | 11.77 | 11.80 | 11.32 | 10.69 |
| OUT | 10.56 | 10.78 | 10.56 | 10.17 | 9.08 | 9.67 | 8.90 | 8.78 | 7.71 |
| Rate (mg/1000/hr) | 20.4 | 16.1 | 36.6 | 48.4 | 76.4 | 67.1 | 88.9 | 86.3 | 103.0 |
| Ammonia-N (ug/l) | | | | | | | | | |
| IN | 2 | 5 | -- | <2 | 3 | 3 | <2 | 3 | <2 |
| OUT | 22 | 19 | 52 | 63 | 67 | 99 | 85 | 103 | 101 |
| Rate (mg/1000/hr) | 0.61 | 0.42 | 1.54 | 1.90 | 1.92 | 2.89 | 2.41 | 3.10 | 3.12 |
| pH | | | | | | | | | |
| IN | 7.66 | 7.58 | 7.71 | 7.77 | 7.74 | 7.73 | 7.73 | 7.77 | 7.82 |
| OUT | 7.58 | 7.59 | 7.48 | 7.45 | 7.37 | 7.21 | 7.41 | 7.31 | 7.29 |

Year II 5500 eggs/tray

| Sample Date | Jan* 10/78 | Jan 27 | Feb 1 | Feb 3 | Feb 7 | Feb 10 | Feb 13 | Feb 20 |
|---|---|---|---|---|---|---|---|---|
| Days From Fertiliz. | 76 | 93 | 98 | 100 | 104 | 107 | 110 | 117 |
| TU °C Days | 616 | 751 | 792 | 808 | 839 | 860 | 883 | 940 |
| Temp. °C | 8.4 | 7.8 | 7.9 | 8.1 | 6.8 | 7.4 | 8.0 | 8.2 |
| Flow (1/min) | 12.1 | 12.1 | 12.1 | 12.1 | 12.0 | 12.2 | 12.3 | 12.1 |
| Diss. Oxygen (mg/1) | | | | | | | | |
| IN | 10.8 | 11.2 | 10.6 | 11.1 | 11.2 | 11.1 | 10.9 | 11.0 |
| OUT | 9.3 | 8.9 | 7.1 | 8.2 | 8.2 | 7.2 | 7.8 | 6.8 |
| Rate (mg/1000/hr) | 41.2 | 57.3 | 88.8 | 71.7 | 75.1 | 94.9 | 78.5 | 101.5 |
| Ammonia-N (ug/1) | | | | | | | | |
| IN | 7 | 13 | 24 | 13 | 19 | 18 | 21 | 25 |
| OUT | 67 | 107 | 175 | 124 | 160 | 175 | 147 | 162 |
| Rate (mg/1000/hr) | 1.00 | 1.76 | 2.84 | 2.13 | 2.64 | 2.98 | 2.41 | 2.58 |
| pH | | | | | | | | |
| IN | 7.61 | 7.53 | 7.43 | 7.60 | 7.43 | 7.43 | 7.53 | 7.42 |
| OUT | 7.50 | 7.28 | 7.16 | 7.30 | 7.14 | 7.08 | 7.19 | 7.07 |

* January 10/78 data was taken for 8 trays loaded at 5500 eggs per tray.